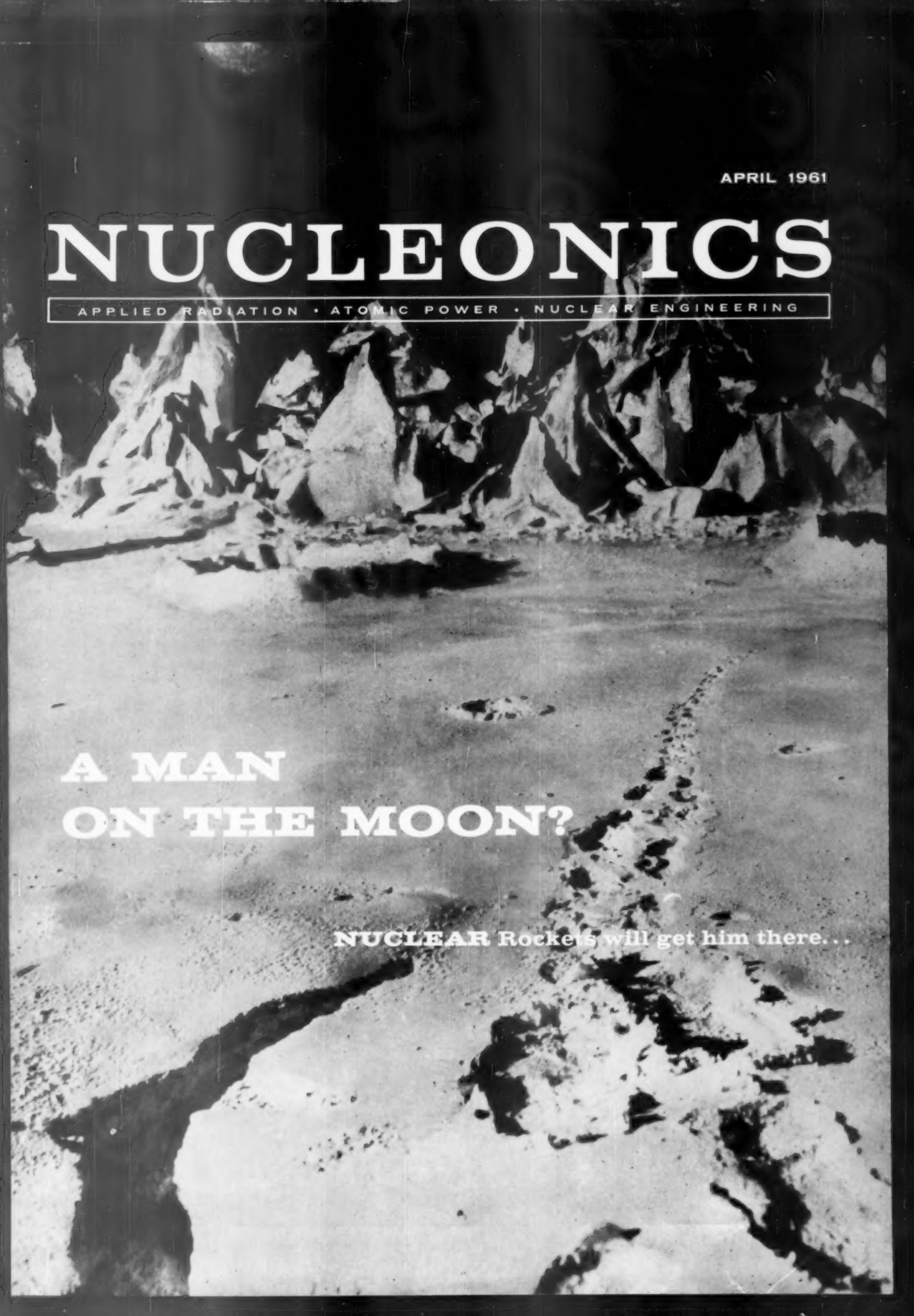
APRIL 1961

NUCLEONICS

APPLIED RADIATION • ATOMIC POWER • NUCLEAR ENGINEERING



A MAN ON THE MOON?

NUCLEAR Rockets will get him there...

NUCLEAR Power will sustain him there

For a comprehensive picture of
"Nuclear Energy in Space"
see 48-page Special Report, p 53

A McGraw-Hill Publication • One Dollar

Find new ways to put the Ato

We've a good mind to do it at

ALLIS

DIVISION

An extremely mobile, lightweight, compact reactor which can produce from 2,000 to 3,000 kilowatts . . .

A nuclear rocket engine to power large Inter-Continental Ballistic Missiles, put great masses into earth orbit, launch space vehicles . . .

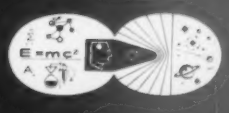
A thermally Regenerative Fuel Cell to light small cities, power magneto-hydrodynamic devices, submarines and space platforms . . .

These are some of the nuclear projects in progress at Allison, with several under government contract.

In their research and development efforts, our atomic scientists and engineers employ such facilities as a vacuum chamber which simulates pressures at altitudes in excess of 200 miles; physical chemistry, solid-state physics, metallurgical and materials laboratories; a liquid metal loop; analog and digital computers and many other research tools. Their efforts are aided by American and European consultants, our Scientific Advisory Committee, plus every resource General Motors possesses.

Whether your problem is concerned with the heavens, the earth or the oceans, Allison has the will and—if it can be solved—the way to solve it. We're doing it for others, we could do it for you.

Shown is heat exchanger section of a nuclear- or solar-powered Stirling-cycle engine under development for space and terrestrial power systems.



ENERGY CONVERSION
IS OUR BUSINESS

e Atom to work?

LISON

DIVISION OF GENERAL MOTORS, INDIANAPOLIS, INDIANA

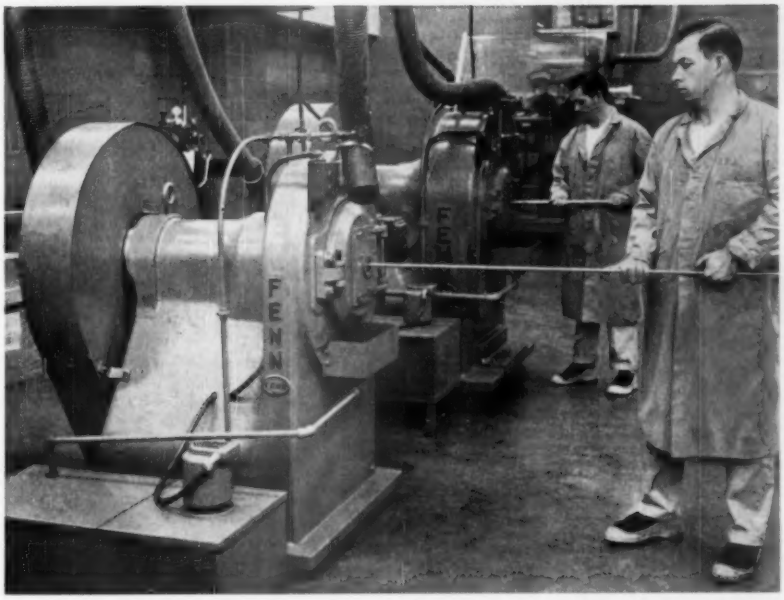
Key positions open for nuclear scientists and engineers. For details, write Mr. V. A. Rhodes, Scientific Personnel Recruitment, Allison Divisi

New B&W Method of Fabrication Promises Longer Core Life

Advanced swaging technique provides higher power output per unit of core volume, improved operating characteristics, longer fuel life.

Babcock & Wilcox is now putting into production a radically new method of fuel element fabrication which promises significant cost savings throughout the reactor lifetime. In this new technique, powdered uranium dioxide is vibrated into thin tubes which are then reduced by swaging to the final diameter. During the swaging process the powdered fuel is compressed to high density, resulting in more intimate and uniform contact between the tube wall and the fuel particles.

Because of their greater uniformity, lower costs, shorter and more predictable fabrication time, the new elements represent an important step toward more economical atomic power.



Operators feed loaded fuel rods into swaging machines at the B&W Nuclear Facilities Plant.

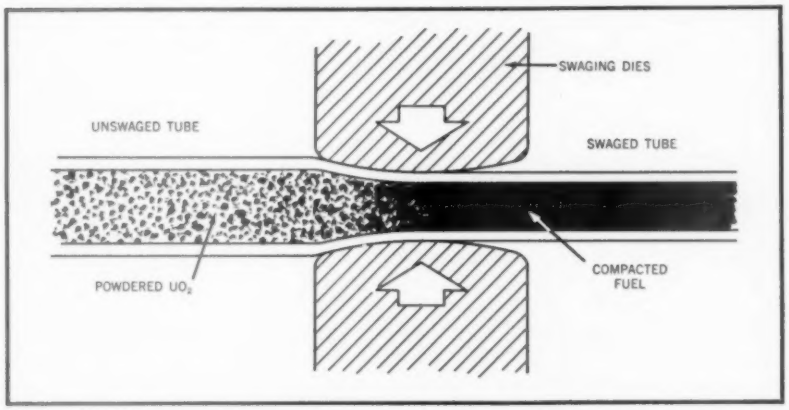
HIGHER POWER OR SMALLER SIZE

Swaged fuel elements reduce the internal resistance to heat flow. Indications are that they can develop higher power than a pellet-type core of the same size – or, can provide equal power from a smaller core.

REDUCED FABRICATION COST

Swaging eliminates all pellet pressing, grinding, and sintering, resulting in substantially lower fabrication costs. It is readily adaptable to loading operations which will be required in the future when handling reprocessed fuels.

For further information on this new fuel element design, contact The Babcock & Wilcox Company, 161 East 42nd Street, New York 17, New York.



Cross section diagram showing the B&W swaging method of fuel rod fabrication.

NC-116

B&W

THE BABCOCK & WILCOX COMPANY

NUCLEAR POWER APPLICATIONS

Vol. 19, No. 4 - April, 1961

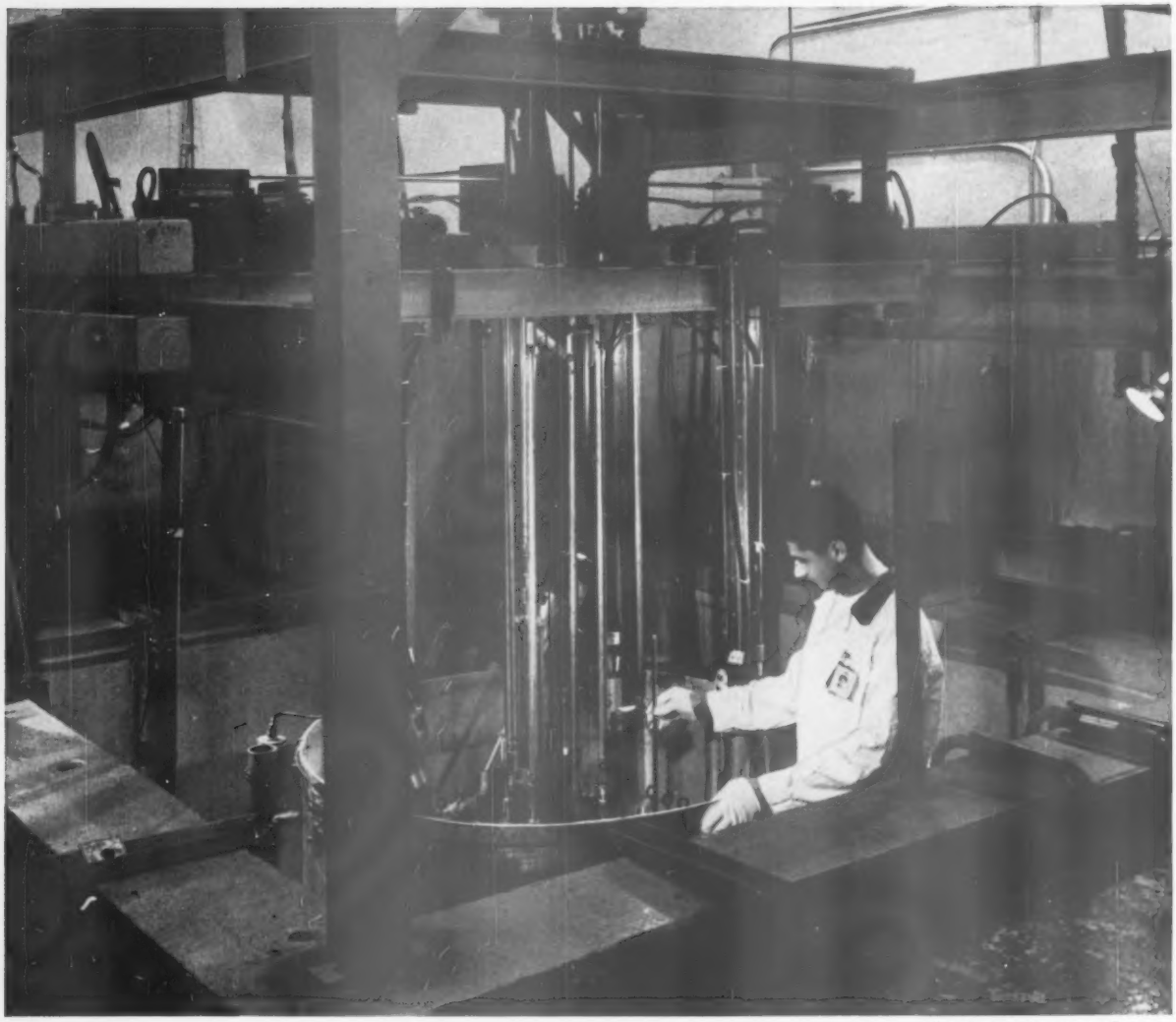


Photo courtesy of The Martin Company

TELEFLEX helps you achieve a simpler, more flexible, more compact control rod drive design!

. . . and saves on total costs. Construction costs. Design costs. Operation and maintenance . . . over the entire life of the installation.

Teleflex Control Rod Drive Systems perform the same function as conventional systems . . . but there the similarity ends. The exclusive Teleflex helical cable is FLEXIBLE—NOT RIGID. Just four basic components comprise this unique system—cable, specially-hobbed drive wheel, gearmotor, and position indication. These few factors alone—plus flexibility of cable and compactness of the entire assembly—open up almost limitless possibilities in reactor design. And makes the designer's task easier and faster.

The Teleflex Control Rod Drive principle is applicable to any reactor design. Cable entry into the reactor can be from top, side, bottom, or at oblique angles. All drive components may be completely outside the reactor, or totally enclosed and remotely controlled.

System simplicity allows first-cost savings of up to 50%. Construction costs go down, too, because vital space within and over the reactor can be held to minimums not possible with cumbersome, more costly systems. Control rods can be placed as close together as 2". Drives can be located as desired for maximum operating convenience and safety to personnel. And Teleflex Cable can reliably handle control rod loads up to 500 pounds. Cable size is selected to meet load requirements.

Teleflex engineers and scientists, trained in the field of nuclear power and research reactors, are ready to discuss your problems and ideas. Write for full information.

TELEFLEX

INCORPORATED • NUCLEAR PRODUCTS DIVISION • NORTH WALES, PENNA.

NUCLEONICS

APPLIED RADIATION • ATOMIC POWER • NUCLEAR ENGINEERING

APRIL 1961 • VOLUME 19 NUMBER 4

A 48-PAGE SPECIAL REPORT

NUCLEAR ENERGY IN SPACE ..... page 33

I—NUCLEAR SPACE PROGRAM

Washington Foresees Major Role for Nuclear Space Power
ROBERT E. L. ADAMSON 54

The Case for Nuclear Energy
HAROLD B. FINGER 58

Nuclear Safety in Space
I. L. BRANCH and J. A. CONNOR, Jr. 64

II—ELECTRIC POWER SOURCES

Radionuclide Power for Space Missions
J. G. MORSE and D. G. HARVEY 69

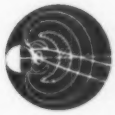
Compact Reactors for Space Power
R. BALENT, J. R. WETCH and H. M. DIECKAMP 73

III—NUCLEAR ROCKETS

Kiwi Tests Pave Way to Rover
RAEMER E. SCHREIBER 77

Nuclear Rocket Reactor Control
R. R. MOHLER and J. E. PERRY, Jr. 80

High-Temperature Materials for Rocket Reactors
DONALD P. MacMILLAN 85



IV—SPACE ENVIRONMENT

Space Radiation Levels
JOHN E. NAUGLE 89

Meteoroid Hazard to Nuclear Spacecraft
ROBERT J. BJORK 91

Space Vacuum Poses Design Problems
LEONARD D. JAFFE 93

Thermal Control in Space Vehicles
T. O. THOSTESEN and P. N. WOLF 94

V—ADVANCED CONCEPTS

Gaseous Propulsion Reactors
ROBERT V. MEGHREBLIAN 95

Thrust From Nuclear Explosions
J. W. EERKENS 100

INSTRUMENTATION & MEASUREMENTS

102 Rapid Flux Mapping in MTR Fuel Elements
ROBERT STEINBERG

106 Gas Chromatograph Monitors Reactor for Fuel Failures
WILLIAM R. KRITZ

NUCLEAR ENGINEERING

110 Scattering Shields for Space Power
CARL N. KLAHR

114 Fast-Reactor Safety Studies in TREAT—A Status Report
C. E. DICKERMAN, E. S. SOWA and D. OKRENT

APPLIED RADIATION

126 Radioautographs Show Quality of Panel Brazing
B. H. FAULKENBERRY, R. H. JOHNSON and E. COLE

132 Recent Advances in Nuclear and Radiochemistry
T. ALEXANDER EASTWOOD

DEPARTMENTS

NUCLEAR REACTIONS 6
NEWS OF THE MONTH 21
NUCLEAR BOOKSHELF 138
PRODUCTS AND MATERIALS 140
EDITORIAL 156
INDUSTRY NOTES 149
NEWSMAKERS 151
NUCLEAR CALENDAR 152
INDEX TO ADVERTISING 155

New Location

Jerome D. Luntz, Editor and Publisher

Daniel I. Cooper, Managing Editor

TECHNICAL STAFF

Thomas L. Cramer, Associate Editor
R. Hobart Ellis, Jr., Associate Editor
Harold L. Davis, Associate Editor
James J. Dutton, Associate Editor
Margaret T. Beach, Assistant Editor

NEWS STAFF

John E. Kenton, News Editor
Robert E. L. Adamson, Associate News Editor
Jon M. Lambert, Assistant Editor

John Wilhelm, Manager, News Bureaus
Washington—G. B. Bryant, Jr., Chief, Richard A. Smith; London—John Shinn, John Tunstall; Paris—Robert E. Farrell, Arthur L. Erikson; Bonn—Peter Forbath, Silke B. McQueen; W. Berlin—Hans Plewe; Moscow—Ernest Conine; Tokyo—Sol Sanders; Rio de Janeiro—Leslie Warren; Mexico City—Peter Weaver; Melbourne—Alicija Grobtuch; Beirut—O. M. Marashian; Brussels—A. P. L. Gordon; Bombay—Sharokh Sabavala; Zurich—Raymond Shah; Johannesburg—Norman Herd; Milan—Gene DiRaimondo; Stockholm—Curt Agren; Vienna—F. H. Baer; Ottawa—Frank Flaherty

PRESENTATION STAFF

Tom Howland, Jr., Art Director
Herbert Taylor, Assistant Art Director
Barbara Keller, Editorial Assistant

Keith Henney, Consulting Editor

•

Philip H. Hubbard, Jr.
Advertising Sales Manager

James H. Thomas, Market Research Manager
James F. O'Brien, Business Manager
Tom Howland, Jr., Promotion Manager
George Pomeroy, Classified Advertising Mgr.

ADVERTISING SALES STAFF

Donald J. Cassidy, New York
Merrill J. Hosmer, Boston
Donald C. Knapp, Philadelphia
Willis T. Smith, Chicago
Thomas K. Cogswell, Cleveland
Frederick R. Whitmore, Los Angeles
Scott Hubbard, Portland
M. Miller, Atlanta
John G. Grant, Dallas
Joseph C. Page, Houston
Jack Patten, Denver
E. E. Schirmer, Dennis McDonald, London
Stanley Kimes, Frankfurt
Michael R. Zeynel, Geneva

•

Thomas L. Cramer, Buyers' Guide Manager
James H. Thomas, Circulation Manager

...about NUCLEONICS

Subatomic Energy and Space

Robert Hutchings Goddard, America's rocket pioneer, displayed some remarkable insights into their nuclear aspects. Listen to Goddard, writing in *1919* on possible applications of rockets that could reach extremely high altitudes: " . . . of the more important matters to be investigated in this region are the following: . . . the nature of the aurora, and (with apparatus held by gyroscopes in a fixed direction in space) the nature of the α, β and γ radioactive rays from matter in the sun as well as the ultra-violet spectrum of this body." So much for anticipating today's researches on the Van Allen belts and other radiation phenomena in space; in a certain sense Goddard also anticipated the application of nuclear energy to propulsion. In this same 1919 paper, discussing the method to be employed in reaching extreme altitudes, Goddard comments: "We are at once limited, since sub-atomic energy is not available, to a means of propulsion in which jets of gas are employed."

MOONMAKERS. Working with plaster of Paris, flour, and rocket models, McGraw-Hill photographers Basken and Menghini, evolved the moon for our cover

To have been alert to the potential of atomic propulsion in the second decade of this century is further tribute to Goddard's genius.

The significance of Goddard's researches on chemical rockets went largely unappreciated. Now that subatomic energy *is* available let's hope that this mistake of history is not repeated. Our 48-page report on "Nuclear Energy in Space" (p. 53) is intended to inform you about the enormous potential that exists in that field and to educate you about some of the techniques that are being developed to exploit it.

We also commend to your attention our editorial views on the pace and funding of the U. S. rocket program. You will find that on p. 156, the last page in the magazine, the new location for our editorial comment.

We Make our Own Moon

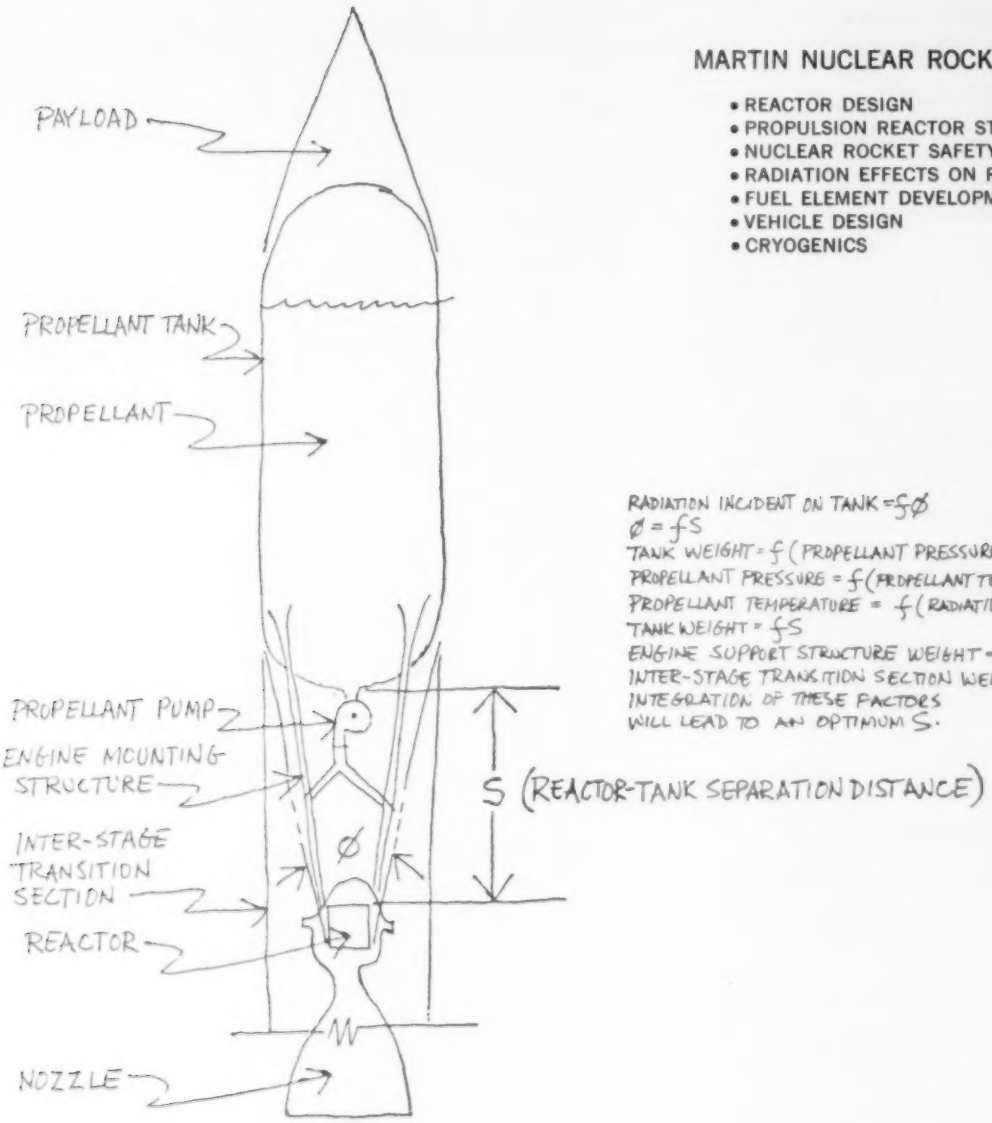
By now you have seen our fancy foldout cover with its evocation of the first man on the moon. It's not really the moon that you see in our photograph. Rather we set up a model of the moon and took a photograph of it. But our moon model was no mere bit of artistic imagination. Our lady-astronomer-editor, Judy Beach, read up on her moonology and gave us information that led to the construction of an accurate plaster model. Then the whole thing was artfully illuminated and photographed as shown below. There will yet be photographs taken on the moon itself; in the spirit of peaceful competition we'd be delighted to carry them before our good friends at *Atomnaya Energiya* do.

—The Editors

A McGRAW-HILL PUBLICATION

NUCLEONICS (with which are consolidated "Atomic Power" and "Atomic Engineering"), April, 1961, Vol. 19, No. 4. Published monthly by the McGraw-Hill Publishing Co., Inc., James H. McGraw (1860–1948), founder. Executive, Editorial, Circulation and Advertising Offices, McGraw-Hill Building, 330 W. 42nd Street, N. Y. 36, N. Y. Telephone: Longacre 4-3000. U. S. subscription rate (includes Buyers' Guide Issue) for individuals in the field of publication: $8 per year; $12 for 2 years; $16 for 3 years; single copies, $1. For subscription details and Canadian and foreign rates see p. 6. Printed and second-class postage paid at York, Pa., U. S. A. Title registered in U. S. Patent Office. © Copyright 1961 McGraw-Hill Publishing Co., all rights reserved. Officers of the Publication Division: Nelson L. Bond, President; Shelton Fisher, Wallace F. Traendly, Senior Vice Presidents; John C. Callaham, Vice President and Editorial Director; Joseph H. Allen, Vice President and Director of Advertising Sales; A. R. Venezian, Vice President and Circulation Coordinator. Officers of the Corporation: Donald C. McGraw, President; Joseph A. Gerardi, Hugh J. Kelley, Harry L. Waddell, Executive Vice Presidents; L. Keith Goodrich, Vice President and Treasurer; John J. Cooke, Secretary.

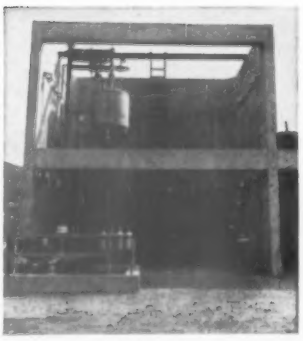
Postmaster. Please send form 3579 to Fulfillment Manager, NUCLEONICS, 330 W. 42nd St., N. Y. 36, N. Y.


PAYLOAD
PROPELLANT TANK
PROPELLANT
PROPELLANT PUMP
ENGINE MOUNTING STRUCTURE
INTER-STAGE TRANSITION SECTION
REACTOR
NOZZLE
S (REACTOR-TANK SEPARATION DISTANCE)
RADIATION INCIDENT ON TANK = fØ
Ø = fS
TANK WEIGHT = f (PROPELLANT PRESSURE)
PROPELLANT PRESSURE = f (PROPELLANT TEMPERATURE)
PROPELLANT TEMPERATURE = f (RADIATION ON TANK)
TANK WEIGHT = fS
ENGINE SUPPORT STRUCTURE WEIGHT = fS
INTER-STAGE TRANSITION SECTION WEIGHT = fS
INTEGRATION OF THESE FACTORS WILL LEAD TO AN OPTIMUM S.

MARTIN NUCLEAR ROCKET PROGRAM

- REACTOR DESIGN
- PROPULSION REACTOR START-UP
- NUCLEAR ROCKET SAFETY ANALYSIS
- RADIATION EFFECTS ON ROCKET SYSTEM
- FUEL ELEMENT DEVELOPMENT
- VEHICLE DESIGN
- CRYOGENICS

THE PROBLEM OF RADIATION HEATING IN NUCLEAR-POWERED ROCKETS



Martin liquid hydrogen test facility at Denver where heat transfer experiments are carried out.

The first flight of a U.S. nuclear rocket is targeted for the mid 1960's; but the achievement of this objective will depend upon the successful solution of many complex technical problems. At Martin, we are investigating all the areas listed above in a coordinated program designed to help solve these problems. An example of one approach to a problem area is illustrated. It concerns the propellant temperature elevation and excessive evaporation that might result from intense radiation created by the reactor.

Martin engineers at Baltimore and Denver are working on several approaches to the solution of this problem: 1) separation between the reactor and the propellant; 2) continuous cooling of certain components by the cryogenic propellant; and 3) shadow-shielding of propellant and components. Optimum solution appears to involve a combination of these alternatives, and can have a substantial influence on overall rocket system weight and performance.

MARTIN

OFF THE SHELF...

semiconductor nuclear particle detectors

ACTUAL SIZE

Never before have revolutionary devices such as these been available from stock . . . for immediate use in nuclear, space, biological, medical and electronic fields.

- ***detection of nuclear particles, (betas, protons, deutrons, tritons, alphas, heavy ions, fission fragaments and neutrons) in or out of a vacuum chamber***
- ***high resolution spectrometry (details are available on SSR's vacuum spectrometry chamber and electronic system)***

The standard transistor three-pin arrangement of the detector packages in SSR's NPS series provide flexibility...two terminals are isolated to permit a choice of signal polarity to the external circuit while the third terminal, connected to the case, permits grounding and shielding.

For complete information on the entire line of detectors as well as special amplifiers and data handling equipment, write SSR.

SOLID STATE RADIATIONS, INC.

9825 WEST JEFFERSON BOULEVARD, CULVER CITY, CALIFORNIA

NUCLEAR REACTIONS

Sodium Trends—Continued

DEAR SIR:

Mr. Davis's letter (NU, March, 1961, p. 7) is most welcome. If any impression was created in the article by myself and J. B. Williams (NU, Jan., 1961, p. 65) that liquid sodium is corrosive in contact with stainless steel, let me hasten to correct it. Mr. Davis's amplification of the Seawolf's uninterrupted performance after palliating the effect of an apparently unfortunate choice of steam-generator materials certainly bears out the sincere belief of the article's authors that sodium-cooled reactors can be made both reliable and highly efficient.

—R. W. DICKINSON, Director
Sodium Reactors Department
Atomics International
Canoga Park, California

DEAR SIR:

The article entitled "Trends in Sodium Equipment" by Dickinson and Williams in the January, 1961, NUCLEONICS, creates a misleading impression of the performance characteristics and limitations of electromagnetic (EM) pumps for sodium and other low-electrical-resistivity liquid metals. The article states that the efficiency of EM pumps is usually $< 10\%$, whereas the efficiency of mechanical pumps is about 80%.

Figures IV-23 and IV-24 on page 294 of ref. *1* show performance data for a linear-induction EM pump rated 3,000 gpm, 75-psi developed pressure, pumping sodium at 580° F. Figure IV-24 shows an efficiency of 45% at rated flow.

Figure 13 of Ref. *2* shows efficiency versus flow in a linear-induction EM pump rated 5,000 gpm, 40-psi developed pressure, pumping sodium at 850° F. This figure shows a test efficiency of 45% at about 4,750 gpm and 43% at 5,000 gpm.

Figure 6 of ref. *2* shows operating characteristics of a mechanical pump also rated 5,000 gpm, 40-psi developed pressure, pumping sodium at 700° F. While the peak pump efficiency is about 77%, the peak over-all efficiency is about 69%. It is interesting to note that the authors of ref. *2* ran extensive comparative tests on the EM pump and the mechanical pump, and that their evaluation of the two pumps was that the EM pump was the more advantageous for the secondary sodium coolant system for Argonne National Laboratory's Experimental Breeder Reactor II.

Dickinson and Williams state further that "temperature limitations (600° F) of electrical insulation on pump coils continue to block high-temperature operation." Reference *2* states that the EM pump windings had never exceeded 160° C during a period of several thousand hours operation at 5,000 gpm, 40-psi developed pressure, pumping sodium at 850° F. The coils in this pump are insulated with class H electrical insulation rated at 200° C hot-spot temperature and capable of operation for long periods at considerably higher temperature. In this design, thermal insulation of $\frac{3}{32}$-in. thickness is interposed between the

Subscription Information

Subscription rates (includes Buyers' Guide issue): United States $8 per year; $12 for 2 years; $16 for 3 years. Canada, other Western Hemisphere countries, and the Philippines, $10 for 1 year; $16 for 2 years; $20 for 3 years; all other countries, $15 for 1 year; $25 for 2 years; $30 for 3 years. Single copy prices: United States, U. S. possessions and Canada, $1, elsewhere, $2; Buyers' Guide issue $2 and $4.

Nucleonics is available only by paid subscription. Publisher reserves the right to refuse nonqualified subscriptions. Subscriptions to Nucleonics solicited only from individuals engaged in the design, development and use of atomic power, nuclear engineering and applied radiation. Position and company connection must be indicated on subscription orders.

Subscription correspondence and changes of address should be sent to Fulfillment Manager, Nucleonics, 330 W. 42nd St., New York 36, N. Y. Allow one month for change of address, giving old as well as new address, and including postal zone number, if any. If possible, enclose an address label from a recent issue of the magazine. Please allow one month for change to become effective.

Our primary aim is to provide subscribers with a useful and valuable publication. Your comments and suggestions for improvement are encouraged and will be most welcome. If editorial service is unsatisfactory, the publisher, upon written request, agrees to refund the part of the subscription price applying to the remaining unfilled portion of the subscription. Printed in U. S. A. Title registered in U. S. Patent Office. **Copyright 1961 McGraw-Hill Publishing Co., all rights reserved.**

duct at 850° F and the electromagnetic structure. Designs for pumping liquid metals at higher temperatures use greater thicknesses of thermal insulation to limit winding temperature.

—Ralph O. Eis
and Ralph G. Rhudy
Motor and Generator Division
General Electric Company
Schenectady, New York

REFERENCES

1. U. S. AEC-Dept. of the Navy, Liquid-Metals Handbook—Sodium-NaK Supplement, TID-5277 (U. S. Government Printing Office, Washington, D. C., 1955)
2. O. S. Seim, R. A. Jaross, in Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy, vol. 7, p. 88 (United Nations, Geneva, 1958)

Dear Sir:

We appreciate the letter from Eis and Rhudy expressing the "mild protest." Note that we stated the efficiency of EM pumps is *usually* less than 10% whereas the efficiency of mechanical pumps is about 80%. We are well aware of the capabilities of the EM pumps to which they refer; the pumps are, however, rather special and as a class, conduction pumps and small linear EM pumps are in the stated efficiency range. Incidentally, it is my understanding that the EM pump in the secondary system of EBR-II was selected on the basis of ease of control rather than efficiency; thermal and mechanical efficiency have not been stated as primary objectives of the EBR-II program.

Eis and Rhudy's comments concerning insulation-temperature limitations are well taken with regard to "cold leg" pumps; many pump applications now require "hot leg" applications and high-temperature insulation in these cases is still a difficult problem. If memory serves me correctly, the EM pumps they refer to were quite complex in their cooling system when operating at 850° F; adequately cooling a pump of this type at 1,150° F would, in my opinion, be considerably more difficult. For large central-station-type power plants, where reduction of parasitic load is economically important, I continue to believe that mechanical pumps are superior to EM pumps in both initial cost, operation and maintenance expense. EM pumps, of course, have a very definite place in the liquid-metal picture and can be used most advantageously in specialized applications, particularly in service systems.

—R. W. Dickinson
Atomics International

A PRIORI
OR
A POSTERIORI?

RCA

ANYWAY YOU LOOK AT IT—RCA Nuclear and Scientific Specialists offer prompt, skilled services to nuclear laboratories and manufacturers.

IT'S A MATTER OF REASONING:

Factory-trained by major equipment manufacturers, RCA's service specialists work from the nationwide network of extensively equipped and stocked facilities . . . to ensure fast, conclusive service that saves you time and money!

AND IT'S A MATTER OF FACT:

Plum Brook—RCA engineers supervised the installation and check-out of control room equipment for the nuclear reactor at the Plum Brook Reactor Facility of NASA, under sub-contract from Leeds and Northrup Company.

HOW CAN RCA SERVE YOU?
• Equipment installation and maintenance
• Complete facility operation
• Specialized engineering assistance
• Training

For A PRIORI information or A POSTERIORI proof, phone WOodlawn 3-8000, Ext. PY 6038, or write to RCA Nuclear and Scientific Services, RCA Service Company, Camden 8, N. J.

IN SAN FRANCISCO BAY AREA, CONTACT:
Donald C. Blair, Manager
141 N. Livermore Avenue
Livermore, California
Hilltop 7-4041

RCA
The Most Trusted Name in Electronics
RADIO CORPORATION OF AMERICA

Tomorrow's weather report will be clear and dependable

THANKS TO WEATHER SATELLITES SUPPLIED WITH AUXILIARY POWER BY COMPACT NUCLEAR REACTORS, meteorologists will be able to make far more accurate forecasts in the not too distant future. By orbiting advanced weather satellites for extended periods of time, forecasters could secure a steady stream of information about changes in the upper atmosphere of the earth. To give these satellites, and other space vehicles, long periods of usefulness, Atomics International is today developing compact nuclear reactors which will provide a lightweight, reliable source of electricity for as long as a year, yet will never need maintenance. At Atomics International there are many other equally challenging nuclear projects underway. *You* are invited to share in this important work.

Immediate opportunities are available in:

STRESS ANALYSIS. Degree plus five or more years of experience either in thermal stress or dynamic stress resulting from shock and vibration loads in aircraft structures. Responsibilities will entail design support for compact nuclear power plants for space applications, including review of all designs with respect to stresses resulting from thermo gradients and transients, static loadings, vibrational and shock loadings.

CORE ANALYSIS. Core analysis of compact reactors including both core statics (criticality, reactivity coefficients, control statics) and stability analysis (core transients, amplitude response, interpretation of oscillator and noise measurements).

SHIELDING ANALYSIS. Analysis of thin shield systems using high speed computers. Proposal of experiments to substantiate calculations and analysis of test results. Degree and three to five years experience required including an understanding of Monte Carlo methods.

THERMOELECTRIC. Electrical engineer with one or more years experience in the development of thermoelectric equipment to originate and develop advanced, light weight thermoelectric equipment for use with compact nuclear power plants for space and other mobile applications.

HEAT TRANSFER. Senior engineer to be responsible for system engineering studies on the thermal, hydraulic and thermodynamic performance of compact power reactor systems.

For specific details write: Mr. C. D. Newton, Personnel Office, Atomics International, 8900 DeSoto Avenue, Canoga Park, Calif.

ATOMICS INTERNATIONAL
Division of North American Aviation

Today's nuclear data require precise dependable time-saving instruments

MODEL ND-130 $12,200*

* FOB MADISON,

NUCLEAR DATA'S

SERIES ONE-THIRTY

ANALYZER-COMPUTER

The Series One-Thirty 512 channel pulse height analyzer is a remarkable new system. It is designed to meet the needs of the radiochemist, physicist, health physicist, biologist and engineer in a manner *never before* possible.

The series 130 analyzer-computer performs the energy distribution analysis of an "unknown" sample. By using standard spectra, or background measurements (previously made by this analyzer, or at other laboratories), it "dissects" the new information by subtracting a fraction of the standard spectra from the new information. This reduction process is commonly performed by large computers and is variously called "peeling", "stripping", or "dissecting". The Nuclear Data Model 120, 512 Channel Analyzer, recently announced, was designed as the foundation of the Model 130 Analyzer-Computer.

In the series 130 system, the new information is "analyzed" (or read from a backlog of new tapes from other analyzers) into the first 256 channels of the memory, and the standard spectrum or background is read into the second half of the memory. The analyzer circuitry allows computation to proceed automatically, at a high rate and without chance of error, at the touch of a button. The rate of computation is such that in the worst case, it could be completed in a small fraction of a second. However, most data reduction problems do not involve a predetermined fractional multiplier. The reduction proceeds step by step, until, in the judgment of the operator, the correct amount has been subtracted or added. This requires that after each operation, the result be automatically displayed as a point-plot on the cathode ray tube screen. The arithmetic has therefore been slowed to a rate which permits the operator to react: Each step is a one second step, with a total of ten steps the average required. The automatic display is useful, because the operator need only touch a button, and is then free to watch the displayed results.

The requirement for human judgment in the reduction process is a distinct advantage. Almost impossible programming difficulties can be involved when external large scale computers are used to reduce data.

Many considerations were involved in the design of the series 130 system. It was recognized that paper tape read-out and read-in must be included as an integrated part of the system. Paper tape systems, rather than magnetic tape, are desirable for many reasons. Visual readability of the tapes, ease of storage, freedom of need to make "endless" tape loops, freedom from synchronization problems, interchangeability of tapes between laboratories or different analyzers, are among these reasons.

Other design considerations have been involved, beyond providing highly convenient and almost "instant" computations without a tape device. Those who have utilized standard spectra in reducing new information are well aware of the need for nearly *perfect* analyzer stability and linearity. Those who have not used standard spectra can quickly appreciate that need by subtracting, graphically or numerically, a gaussian "peak" from another of the same shape and area, displaced just slightly. In analyzer terminology, if a photopeak centered in channel 100 is subtracted from a similar photopeak centered in channel 99, the result is quite "messy". To deal with this problem, great care has been taken in the design of the analyzer circuits, to provide excellent stability and linearity.

Dependability, ease of operation, circuit accessibility, mechanical ruggedness, portability (for easy carrying from place to place, as distinguished from

field use), and general versatility have been carefully considered.

Here are a few of the uses which can be made of the data reduction capabilities. The commonest use is in subtraction of background from new measurements. The earlier analyzers provided a "spectrum transfer" operation, which allows negative background to be transferred into an empty memory. The new information was analyzed "on top" of this, to provide background corrected data. This process, requiring background measurements of the same duration as the expected new measurements, is inconvenient. It dictates that all measurements, using that background measurement, be of a *fixed* duration regardless of the activity of the sample involved in the new measurements. This method introduces statistical errors which are frequently comparable to those in lower activity energy regions of the new data. With provisions for multiplying by any constant, a long, accurate, background measurement can be made, using the series 130 system. Any desired amount of this measured background may be subtracted from the new data. Statistical errors are greatly reduced. The new measurements may be timed appropriate to sample activity. The subtraction process can be made after, rather than *during* analysis.

The use of the series 130 system in "peeling" operations is its most important application. This application is well known, though previously not available to most laboratories. Many variations will be made in its application.

Another incidental use of the multiplier capability is in normalizing spectra, to allow comparison of two spectra in the "display overlap" readout mode, or in recording two spectra.

The series 120 analyzer is identical to the series 130 analyzer-computer, except for the data reduction capability. It is designed to be readily converted to the series 130. The final cost of this conversion is equal to what would be incurred if the series 130 analyzer had been purchased originally. If budget limitations do not permit purchase of the complete series 130 system, *no* sacrifice of future capability need be made.

As a "minimum" system, the series one-twenty analyzer is a superb analyzer, which can be converted to series one-thirty without penalty at a later time. Even as a complete system, *with data reduction capabilities*, typewriter readout, paper tape punch and reader, and display oscilloscope, the series 130 system is no more expensive than competitive analyzers which do not have tape handling and data reduction capabilities.

The quality of the components, and the excellence of the engineering, overall and in detail, are simply not matched in *any* analyzer, whatever the cost.

HERE IS ONE APPLICATION

Problem: What is the activity of the cesium 137 component in a mixture also containing cobalt 60?

Solution:

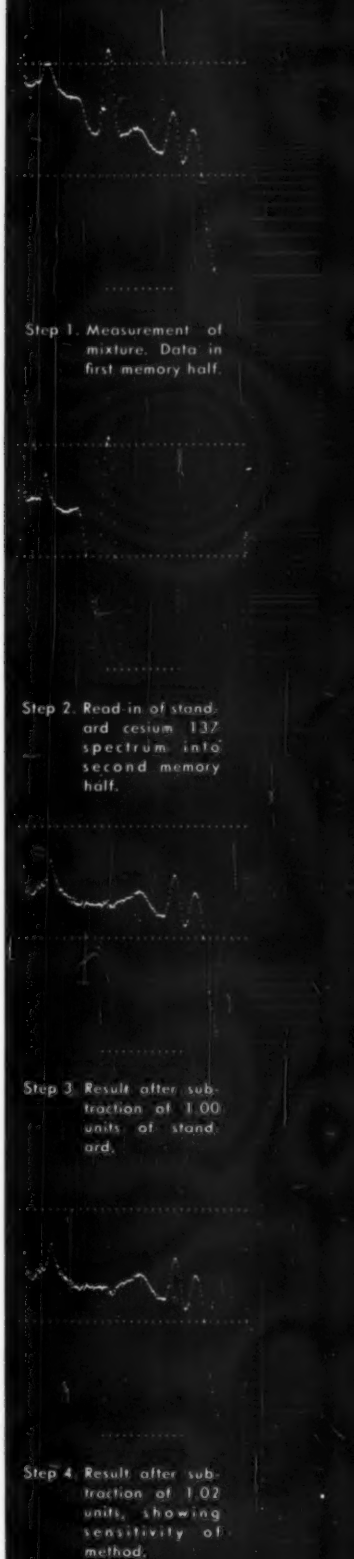
1. Measure sample, using a standard sample-source geometry, and arbitrary but accurately measured live time. Use first 256 analyzer channels for storage of data.

2. Read into second 256 channels a standard spectrum of cesium 137, previously recorded on punched paper tape. This spectrum will be utilized as an absolute standard of activity. The same geometry and energy scale must be used and an arbitrary, but also accurately measured, live time should be indicated.

3. Subtract, by trial, any fraction of the standard spectrum from the new spectrum of the mixture, until the cesium 137 component vanishes. This subtraction is made by selecting a suitable decimal multiplier, and touching the "initiate computer cycle" button.

Answer:

In this illustration, the "unknown" was really known in advance. It consisted of two separate samples, one of cobalt 60, and the other a 0.6 microcurie cesium 137 source. The decimal fraction necessary to cause the cesium 137 component of the "unknown" to vanish was 1.00, since the standard spectrum was one made by measuring the same cesium source for an equal length of time. The illustration shows the method which may be used in determining activity by means of a standard spectrum, but more important, it indicates that the series one-thirty analyzer exhibits the very important characteristics of virtually perfect freedom from gain shift, zero shift, and live time determination error, which changes in counting rate so often introduce. Although the counting rate increased by more than a factor of two, during the measurement of the mixture, there was less than a twentieth of a percent shift in photopeak position, for even such a small shift, in this experiment, would have introduced a noticeable "wiggle" in the remnant spectrum, at the .662 m.e.v. region.



Step 1. Measurement of mixture. Data in first memory half.

Step 2. Read-in of standard cesium 137 spectrum into second memory half.

Step 3. Result after subtraction of 1.00 units of standard.

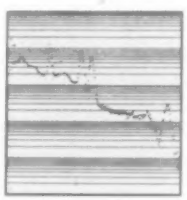
Step 4. Result after subtraction of 1.02 units, showing sensitivity of method.

NOTE: *These are unretouched Polaroid photographs reproduced actual size.*

A few big reasons why Nuclear Data Analyzers are the best for most needs . . .

1. The ND-130 analyzer-computer reduces data *internally*. This is the way to handle the problem, because:
   a. The arithmetic computations are 10 times faster than with an external "stripper" using magnetic tape as a memory element. We get this speed advantage by using one-half of the ND-130 internal memory. Complete reduction of a spectrum can be accomplished in seconds, not minutes.
   b. The paper tape input-output of our analyzers can "talk" to and from other analyzers and computers. Magnetic tape is usually not compatible with other analyzers and computers.
   c. Paper tapes can be visually "read" for verification or identification. Storage and handling is easier.
   d. Computation proceeds at the touch of a finger; data is displayed in precise logarithmic form *automatically* at the end of each trial operation, for quick and easy inspection of results.
   e. The spectrum of interest, and information to be subtracted or added, can be displayed in the "overlap" mode without extra operations. This eliminates errors which can occur in "blind" operation.
   f. There is no mechanical magnetic tape transport equipment, and therefore there is no synchronizing problem.
2. The ND-120 and ND-130 have a wide range of energy coverage in each measurement. The 32 k.e.v. barium x-ray line is fully resolved with a gain setting of 2.7 m.e.v. full scale. This means that:
   a. A standard energy scale can be used for most measurements, rather than a different scale to suit particular measurements. This allows easier cataloging of results, fewer "standard" spectra to file for data reduction purposes. Where energy coverage is only half as good, scale standardization is not practical in many cases.
   b. Almost no measurement need be repeated because of failure to record the whole spectrum in a single measurement.
3. The series 120 and 130 analyzers have the most precise logarithmic readout of any analyzer. Perfectly positioned, automatically generated decade lines, movable to different positions at the touch of a button, permit accurate quantitative inspection of regions of interest. The display is free of ripple, and points are sharp and clear. This readout is important because:
   a. Comparisons of spectra taken for different lengths of time are difficult if linear display is used. The shape of the spectrum varies with counting time, whereas the shape of the spectrum, plotted or displayed *logarithmically* in our analyzers, is not a function of measuring time or source activity. Only the vertical position of the whole curve varies with time or source strength in a *logarithmic* presentation, except for statistical variations.
   b. Logarithmic readout permits the whole range of activity to be displayed without range switching. Normalization is not ordinarily required, but in the series 130 analyzer, normalization can be accomplished by multiplication by any constant.
   c. Published data are usually in logarithmic form. Both report preparation, and use of other persons' reports are easier if logarithmic presentation is used.
4. The series 120 and 130 analyzers are of proven design. These are the only new analyzers based almost completely on a successful predecessor. In logic and circuitry, only relatively small alterations have been made in order to improve upon the performance of the series 100 analyzers. More than a dozen such improvements, and repackaging to provide greater mechanical ruggedness and simpler cooling, are expected to result in an unmatched overall dependability.
5. The complete series 130 system can be built up step by step, without penalty. A basic analyzer series 120 can be purchased initially. When additional funds become available, the series 120 can be converted to a series 130 analyzer-computer. Conversion cost, except for the minor costs of shipping, is the same whether purchased as a complete system initially or built up step by step. The no-extra-cost conversion of the series one-twenty analyzer applies only for 3 months after delivery, after which a charge is made for the conversion, beyond the "difference in initial price" charge.
6. Nuclear Data specifications are conservative. The specification on live timer precision (1%) is an order of magnitude reduced from what we think the precision actually is, based upon numerous tests. Linearity of plus or minus ½% of full scale is at least a factor of two reduced from what tests indicate. Temperature limits are well under the test conditions used in production.
7. Nuclear Data delivers. The series 120 and 130 analyzers were *not* announced in advance of completion of preliminary engineering. These analyzers have been designed, tested, and are finished products.
8. The series 120 and 130 analyzers are small, light and portable, yet not overminiaturized. Easily replaced circuit boards are all accessible, without removal of boards, and without use of extenders. Temperature rise inside cabinet is 3°C without the use of vent-holes or fans; heat dissipation is 5 milliwatts per square inch of cabinet surface. In-place accessibility is a feature of major importance.
9. The series 120 and 130 analyzers cost less than any other analyzers of comparable memory capacity, count capacity per channel and readout facilities. This is true not only of the basic analyzers but also in complete systems including tape punch, input and output controls, typewriter and display oscilloscope.

NUCLEAR DATA INC.



3833 WEST BELTLINE HY. MADISON / WISCONSIN

HARSHAW MANUFACTURES A COMPLETE LINE OF SCINTILLATION AND OPTICAL CRYSTALS

SCINTILLATION *Mounted* NaI(T1) *Crystals*

Crystal detectors designed for the most sophisticated counting problems. Our physics and engineering group are available to assist you in your special detector problems.

More detailed information is contained in our 32-page book, "Harshaw Scintillation Phosphors". We invite you to write for your free copy!

STANDARD LINE

(Hermetically Sealed Crystal Assemblies)

- The accepted standard of the industry
- Proven through years of service in research, medical and industrial applications
- unparalleled performance
- dependability
- consistent good quality

INTEGRAL LINE

(Crystal photo multiplier tube combination assembly)

- Improved resolution
- Ready to use plug-in unit
- Permanently light sealed
- Capsule design facilitates decontamination
- Close dimensional tolerances
- Harshaw guaranteed

Large Crystal MATCHED WINDOW LINE

(Designed primarily for crystals 4" dia. and larger)

- "Small crystal" performance achieved through improved optical design
- Low mass containers
- Available in standard aluminum or complete low background assemblies
- Convenient mounting flange
- Ready to use

Every Harshaw crystal is a product of our experience in crystal growing technology since 1936

Other Phosphors Available from The Harshaw Chemical Company

ROUGH CUT THALLIUM ACTIVATED SODIUM IODIDE CRYSTAL BLANKS • EUROPIUM ACTIVATED-LITHIUM IODIDE (NORMAL) • EUROPIUM ACTIVATED LITHIUM IODIDE (96% Li^6 ENRICHED) • THALLIUM ACTIVATED CESIUM IODIDE • THALLIUM ACTIVATED POTASSIUM IODIDE • ANTHRACENE • PLASTIC PHOSPHORS

OPTICAL *Crystals*

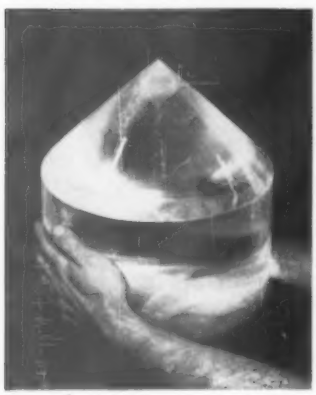
For Infrared and Ultra Violet Transmitting Optics

"HARSHAW QUALITY" INHERENT IN EACH HARSHAW-GROWN CRYSTAL GUARANTEES THE MOST EFFICIENT OPTICAL TRANSMISSION POSSIBLE THROUGH:

1) Negligible light scattering in crystals, permitting higher sensitivity and improved resolution
2) Freedom from absorptions caused by trace impurities in crystal optics
3) Minimum strain

"HARSHAW QUALITY" meets the demand for uniformity of optical properties such as dispersion and refractive index.

Prices, specifications, or other information will be sent in answer to your inquiry.



The following infrared and ultra violet transmitting crystals are available; others are in the process of development:

SODIUM CHLORIDE • SODIUM CHLORIDE MONOCHROMATOR PLATES • POTASSIUM BROMIDE • POTASSIUM BROMIDE PELLET POWDER (through 200 on 325 mesh) • POTASSIUM CHLORIDE • OPTICAL SILVER CHLORIDE • THALLIUM BROMIDE IODIDE • LITHIUM FLUORIDE • LITHIUM FLUORIDE MONOCHROMATOR PLATES • CALCIUM FLUORIDE • BARIUM FLUORIDE • CESIUM BROMIDE • CESIUM IODIDE

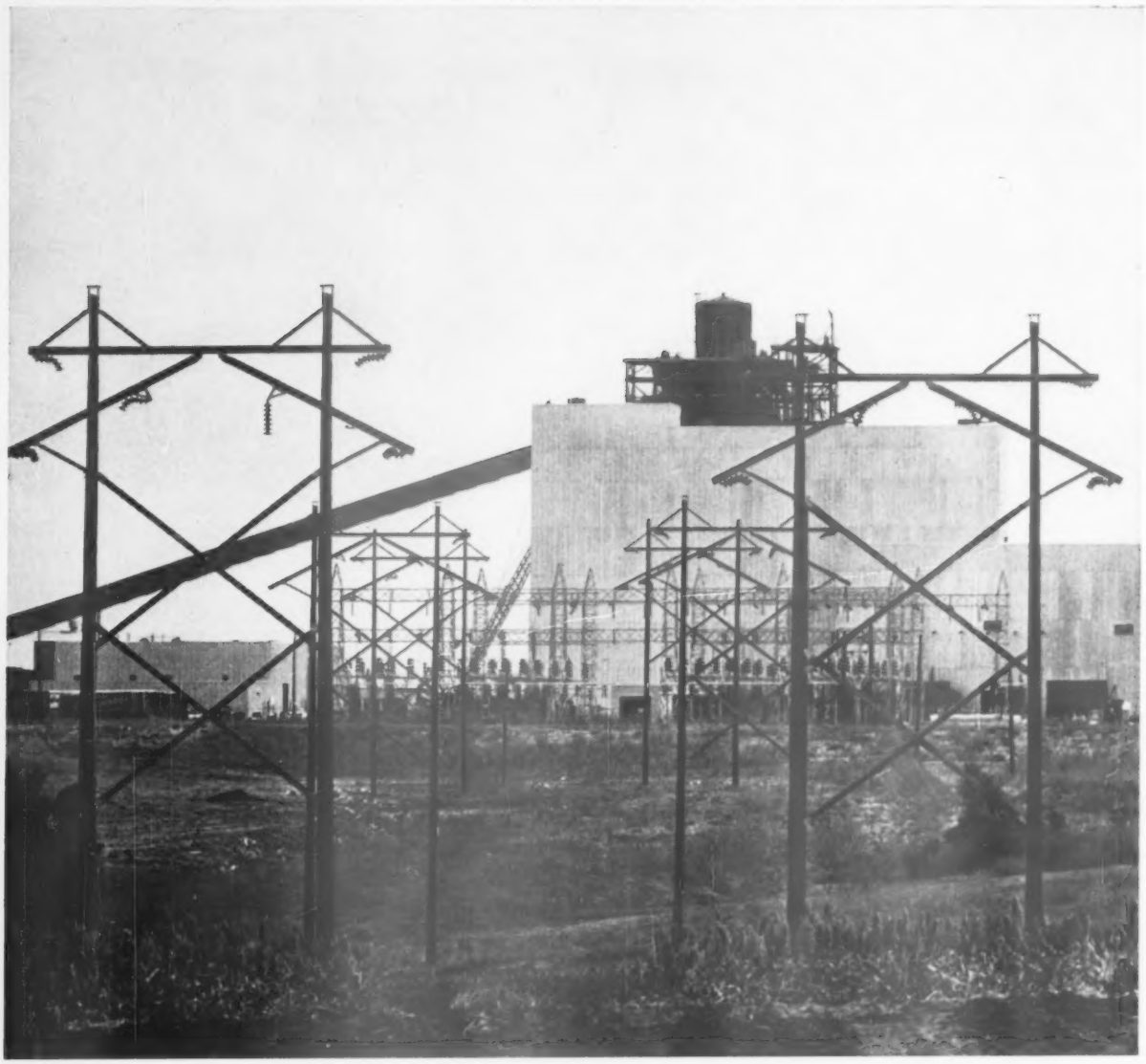
Additional information on the physical and optical properties of the above crystals is available in our 36-page booklet "Synthetic Optical Crystals". Send for your free copy.

HARSHAW

THE HARSHAW CHEMICAL CO.

Crystal Division • Cleveland 6, Ohio

75,000 KW Sodium Graphite Reactor station for Consumers Public Power District at Hallam, Nebraska



The Peaceful Atom

Helping the world double its power supply in the next ten years

The fuel of the future is in the atom. But even now, lights are burning, wheels are turning, thanks to atomic fuel. Atomics International, a world-wide leader in advanced, high-performance reactor systems, has over 15 years' experience in designing, constructing, and operating reactors. Two of the world's most advanced atomic power stations are now being built by AI under AEC programs. The wealth of experience and facilities at Atomics International will help the world's power-producing companies in their plans to double the supply of electricity in the next ten years.

ATOMICS INTERNATIONAL

Division of North American Aviation

Pioneers in the creative use of the atom

World Headquarters: Canoga Park, California, U.S.A. Cable Address: ATOMICS. *Other offices:* Washington, D.C., U.S.A.; Geneva, Switzerland. *Affiliated with:* INTERATOM, Bensberg/Cologne, Federal Republic of Germany and DYNATOM, Paris, France

GLC GRAPHITE SERVES NUCLEAR REQUIREMENTS

Throughout the World

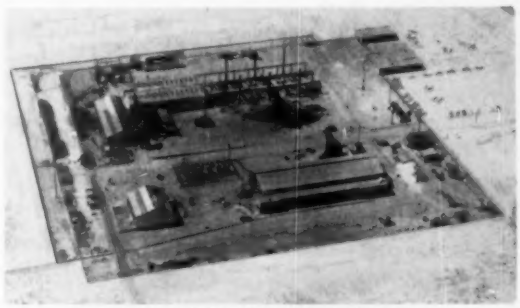
GRAPHITE PLANTS OF THE ELECTRODE DIVISION
GREAT LAKES CARBON CORPORATION

Morganton, North Carolina

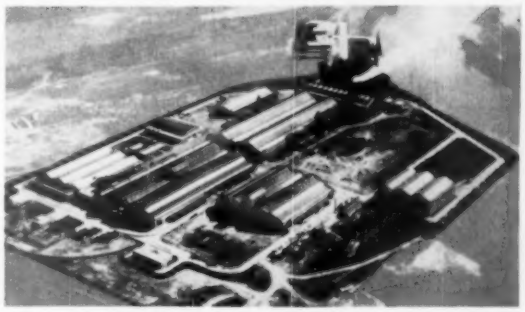
Niagara Falls, New York

The uniformly high quality of GLC graphite for nuclear applications has been proved in thermal columns and reflectors in operation throughout the world, as well as in sub-critical assemblies operated by leading American Universities.

We are equipped and staffed to supply a superior graphite promptly and economically for nuclear applications of all kinds. Our facilities for expediting both domestic and overseas shipments are excellent.



Antelope Valley, Lancaster, California



ANGLO GREAT LAKES CORPORATION LIMITED
Affiliate of Great Lakes Carbon Corporation
Newburn Haugh–Newcastle upon Tyne, England

For an introduction to GLC graphite—and to one of the world's outstanding graphite producers—write for a free copy of our illustrated brochure, "Graphite For Diversified Industrial Applications".

PRODUCTS GLC YOU CAN TRUST

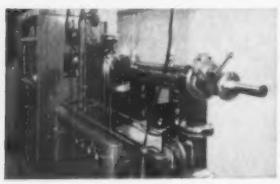
GREAT LAKES CARBON CORPORATION

18 EAST 48TH STREET, NEW YORK 17, N.Y.
OFFICES IN PRINCIPAL CITIES

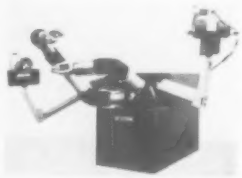
Nuclear Radiation & Electronics:

Just what part does Hughes play?

It all started some six years ago. As a leader in military and commercial electronics, Hughes was keenly aware of the vital inter-relation between nuclear technology and electronics technology. ■ The specific question which Hughes engineers sought to answer was, "What are the effects of nuclear radiation on electronic systems?" ■ To answer this question, Hughes brought together leading scientists in both the nuclear and electronics fields. ■ In the process of solving this problem, these scientists and engineers became acutely aware of the need for adequate equipment for radiation generation, measurement and handling. They proceeded to develop these badly needed devices—both to solve their own problems, and to make them commercially available. ■ The linear accelerator is a typical example. The need to accurately simulate the gamma radiation from nuclear detonation was apparent. So, Hughes developed and built the first gamma accelerator with variable pulse widths, a high repetition rate, and a high peak electron beam current (over 1 amp). For more extensive investigation of the nuclear environment, Hughes also builds a pulsed reactor for the simulation of neutron radiation. ■ Radiation detection devices that were faster, more compact, and more versatile were also needed. This problem was solved when Hughes scientists developed an incredibly small (2 mm square) solid state detector with better than 1% resolution and response time of less than 1 nanosecond. ■ Remote handling of highly radioactive objects was another problem examined by Hughes. In designing radiation research facilities for the investigation of nuclear radiation effects, novel applications for proven electronic control techniques were found. One result was the Hughes MOBOT*, a completely remote controlled handling machine using TV vision and electronic controls. ■ So, what part does Hughes play? Hughes specializes in nuclear radiation—analysis of effects, and products for its generation, measurement and handling. If you have a radiation problem, we would like to talk to you about it. Write, wire or call collect: HUGHES NUCLEAR ELECTRONICS LABORATORY, P.O. BOX 90915, LOS ANGELES 45, CALIF., TWX INGL 4036, ORCHARD 0-1515, EXT. 5355.



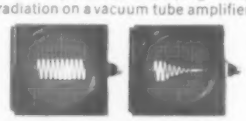
Hughes High-Current Linear Electron Accelerator



Hughes MOBOT Mark II for remote controlled handling

Hughes Solid State Nuclear Radiation Detector

Effect of pulsed (low dose, high rate) radiation on a vacuum tube amplifier



Radiation Off Radiation On

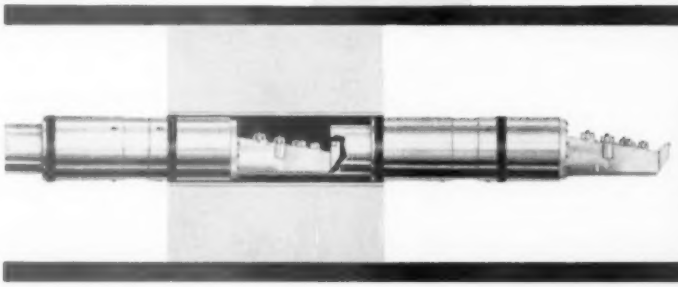
*Trademark of H. A. C.

HUGHES

NUCLEAR ELECTRONICS LABORATORY
HUGHES AIRCRAFT COMPANY

NEW . . . for high-level alpha-gamma hot cells—for handling pyrophoric, highly toxic gaseous or airborne particulate materials—wherever complete atmospheric control, prevention of dissemination by explosion or other accident is essential . . .

complete containment is provided by central research model A sealed manipulators



Sensitive and reliable, Model A manipulators are designed for dextrous, positive control and complete containment with shielded enclosures.

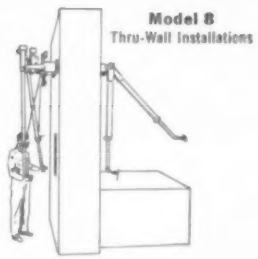
CONSIDER THESE IMPORTANT FEATURES:

SEALS—Double rotary mechanical seals between master and slave mechanisms insure reliability. Space between seals may be pressurized to monitor seal integrity. One seal is always operative even when changing seal tubes. "Push-thru" seal-tube replacement technique does not require complete wall port opening. Seal-tube features mean that all contaminated assemblies remain inside cell for disposal or decontamination and need never be brought out to the operating face.

OPERATION—Careful counterbalancing, reduction of mass, friction and lost motion make forces in the ounce range sufficient to initiate all motions. Easily handles 20-pound load per arm. Bilateral drive and force reflecting design characteristics give remarkable "sense of feel," reducing training time to a minimum.

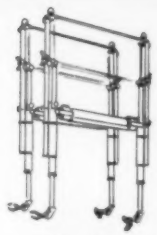
MAINTENANCE—Three standard, interchangeable subassemblies: master arm, slave arm, and seal tube, simplify maintenance. A crane and simple fixture are sufficient for remote connection or removal of slave arm. Alignment pins assure positive slave arm positioning. All slave-end motions lock at disengagement for easy relocation.

CENTRAL RESEARCH . . . MANIPULATORS FOR EVERY NEED



Model 8
Thru-Wall Installations

Model 7
Restricted Space Installations



Model 4
Over-Wall Installations

Model B
Canal Manipulator

For further information write:

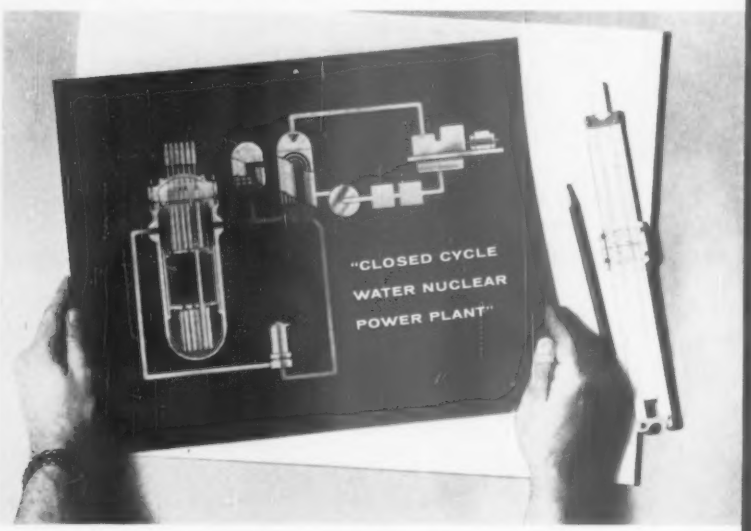
Central Research
laboratories, inc.
Red Wing, Minnesota, Dept. 110

ON THE LINE

Yankee—a Westinghouse achievement of the first order in its continuing effort to bring atomic power to its full commercial capabilities.

ON THE BOARDS

the new 375-Mwe atomic power plant is a giant step forward in the realm of controlled commercial nuclear power. Projects like this offer to professional personnel the opportunity to take part in the design and development of economic nuclear power plants. Career openings for qualified scientists exist in many areas. Some of these areas are listed in the next column.



Westinghouse

ATOMIC POWER DIVISION

FIRST IN ATOMIC POWER

HEALTH PHYSICIST:

To direct and perform health physics and industrial hygiene work at various WTR facilities. Work will also include non-health physics engineering that pertains to reactor and hot lab work. Must have A.B. or B.S. degree and additional training in health physics.

SENIOR ENGINEER:

To assume responsibility for the engineering design and performance of experimental high pressure, high temperature systems both for in-pile and out-pile programs. Position would involve design of high pressure equipment, heat transfer, fluid flow and stress analysis of piping systems. B.S. degree in Mechanical Engineering or Chemical Engineering with a minimum of 10 years experience in related fields.

SENIOR ENGINEER:

Alloy development on reactor materials and fuels with particular emphasis on control rod and cladding materials. M.S. degree in metallurgy with three years experience in reactor materials.

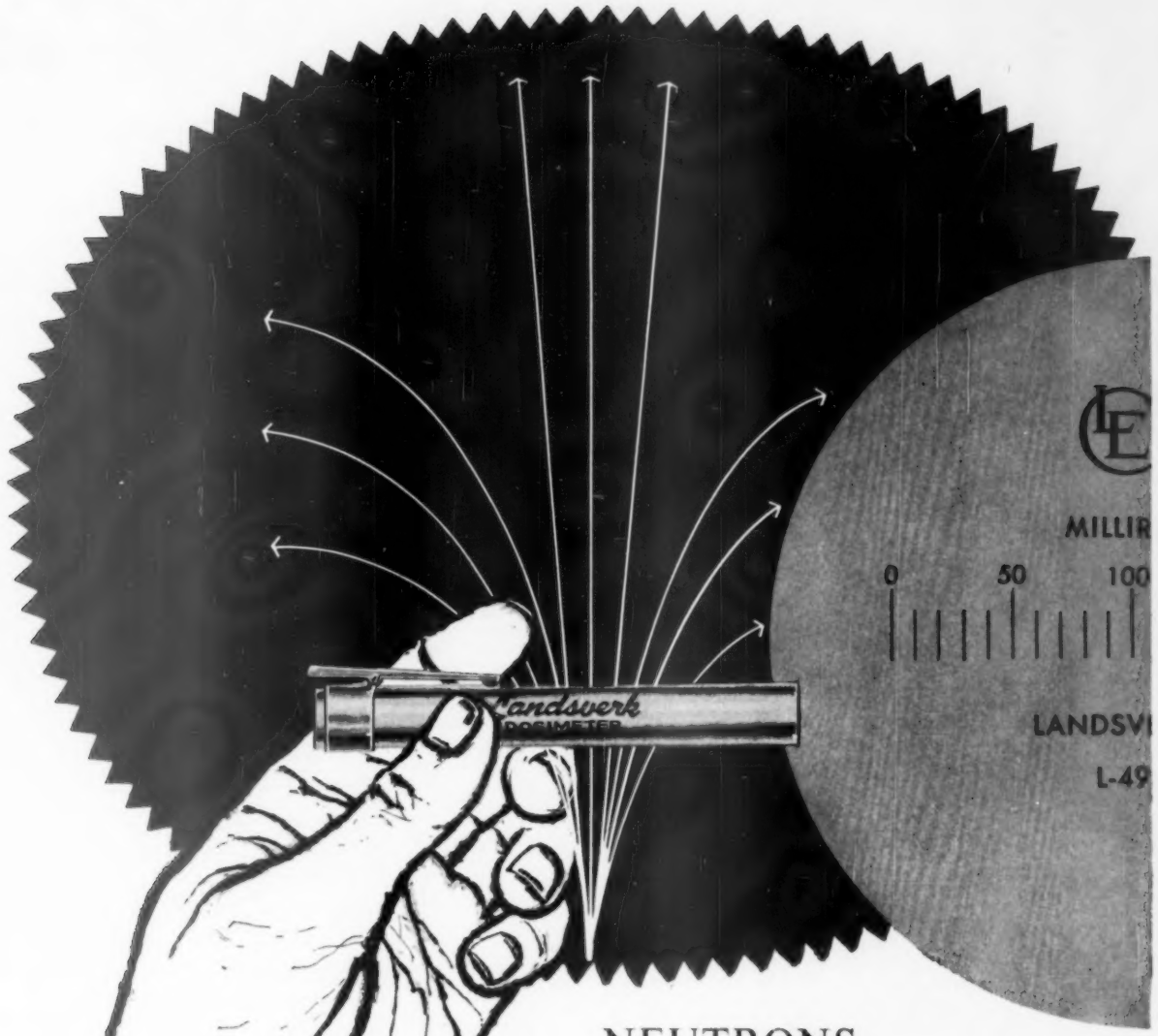
PROJECT ENGINEER:

To assist customers in the preparation of experiments to be performed in the testing reactor. Includes design of capsules, heat flow and fuel burnup. Also, calculations and liaison with customer engineers during course of the experiment. B.S. degree in engineering with related nuclear experience.

ENGINEER OR SCIENTIST:

To perform reactor physics calculations on reactor cores which involves problems of the development and application of theoretical methods, founded on basic theory, to technical programs concerned with the design and construction of large power reactors. M.S. degree in physics or nuclear engineering.

If you qualify for any one of the above positions, write immediately to: Mr. C. S. Southard, Westinghouse Atomic Power Division, P.O. Box 355, Dept. X-82, Pittsburgh 30, Pennsylvania.



NEUTRONS
GAMMA RAYS
X-RAYS

are accurately measured by the

Landsverk Model L-49 200 MREM

Thermal Neutron Dosimeter

Write Dept. C for free catalog.

Landsverk Electrometer Company

641 SONORA AVE., GLENDALE 1, CALIFORNIA

FIRST NAME IN DOSIMETERS FOR MORE THAN A DECADE

PLATR

Predicts Neutron Behavior of D_2O Moderated Reactors

QUICKLY ACCURATELY INEXPENSIVELY

WHITE PLAINS, N.Y.—PLATR (Pawling Lattice Test Rig) plus only a small sample of uranium is quickly and inexpensively predicting detailed and precise data on neutron behavior in heavy water moderated reactors. Installed in the NDA Pawling Research Reactor (PRR), PLATR is a unique research facility designed, built and operated by NDA as part of a cooperative USAEC-Canadian D_2O reactor development program.

PLATR's outstanding feature is its flexibility, both in the number of variables it can accommodate during a test program and in the length of time required to change from one test configuration to another. Removal of cover and upper fuel assembly (fig. 1), the test fuel section (fig. 2), and replacement of these units takes only 10-15 minutes. Complete change-over, which includes draining and refilling of 6,500 pounds of D_2O, takes only 60-75 minutes. The D_2O drains into a tank below the reactor during change-over of test fuel section.

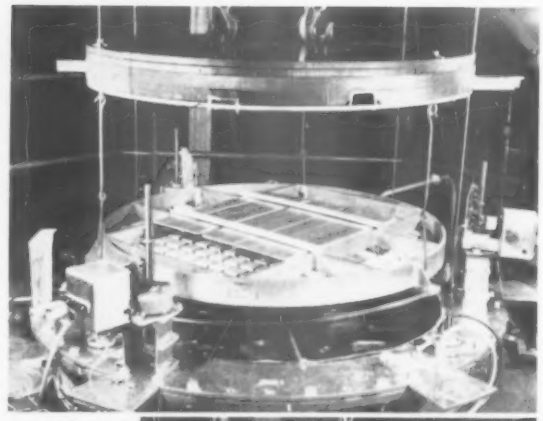
PLATR contains five discrete but interlocking fuel regions. An infinite size reactor core is simulated through simple adjustment of fuel elements, which permit lattice pitches ranging from 7 to 15 inches. Figure 3 clearly shows the various fuel regions and ease with which pitch adjustments can be made.

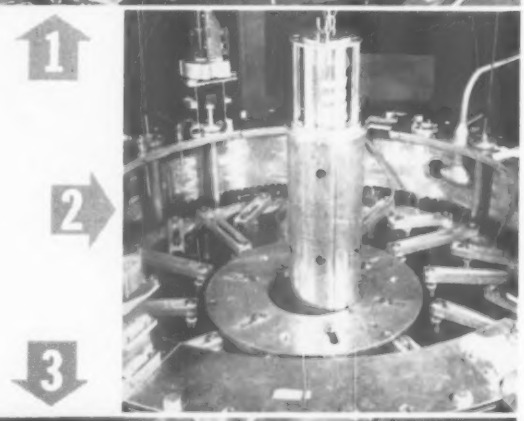
Experiments are being performed with PLATR fuel arrangements in which the nuclear effects of engineering variables are determined. Variables in addition to lattice pitch include fuel element and housing configurations, materials and void volumes. Nuclear measurement of k_∞, Δk, thermal utilization factor (f), and void and moderator temperature coefficients are made. Resonance escape probability (p) and the fast fission factor (ε) may also be measured.

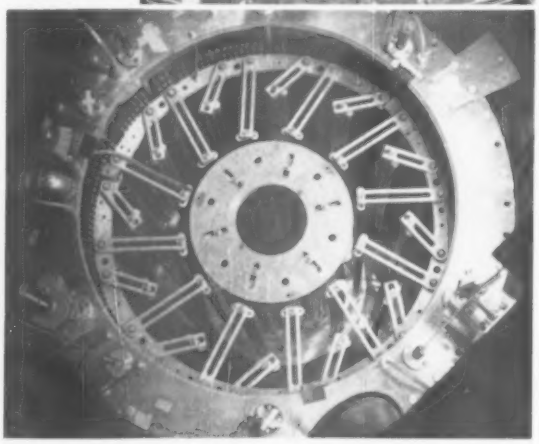
Initial phases of the test program encompass the broad area of fuel rod bundle type elements. Long range plans include testing of concentric tube and multi-plate type fuel elements.

It takes the experience of many years and many people to achieve the valuable goal of utility through application of advanced technology. For a truly professional approach to research, development and application, look to NDA, where tomorrow's advances are being worked on today.

Current and prospective contracts at NDA involving the AEC, NASA, the Departments of the Army, Navy, Air Force, and private industry, provide a healthy growth climate and career opportunities for qualified scientists and engineers. Apply a professional approach to your career—research these opportunities for you at NDA. Write in confidence to Director, Professional Personnel.







NDA **NUCLEAR DEVELOPMENT CORPORATION OF AMERICA**

WHITE PLAINS, N. Y. TEL. WH 8-5800 / NDA EUROPE 31, RUE DU MARAIS, BRUSSELS, BELGIUM

NUCLEONICS NEWS OF THE MONTH

202: Hearings Highlight Nuclear Month in Washington

Washington was the focus of nuclear-energy news last month as it has not been since the exciting days of the running feud between former AEC Commissioner Lewis L. Strauss and the Joint Committee on Atomic Energy.

At JCAE, the witness turnout for the annual "202" State-of-the-Atom hearings was the biggest, best and most interesting in years.

At the House Committee on Science and Astronautics, in the most extensive public hearings ever held on the nuclear rocket, witness after witness asked recognition of this system as one of the most urgent in the U. S. space program (*page 24*).

And at AEC, the reactor-siting crisis was forcing the Commission to take another look at its partnership program for construction of demonstration power reactors.

Contributing to the almost electric air in nuclear Washington were: the excitement of the Kennedy Administration itself; new leadership at both JCAE, where Rep. Chet Holifield (D-Cal.) assumed the chairmanship, and AEC, where the Commission was getting its first scientific chairman, Glenn T. Seaborg; the naming of another scientist to a Commission seat—Leland J. Haworth, director of the Brookhaven National Laboratory; and AEC approval of an internal reorganization (*see page 31*) effecting a staff-level separation of its regulatory and promotional roles (NU, March '61, 26).

202: Disagreement on Capitol Hill

Much of the 202 hearings were given over this year to reports from industry and government officials, at JCAE's request, on materials technology—especially those under development for high-temperature reactors. Nevertheless, the testimony on reactor projects and reactor policy—from both AEC and industry witnesses—was, as usual, the hearing highlight. Particularly interesting in this area was the emergence of three different views among reactor-industry executives on power-reactor status and outlook: 1. that the industry is about where it should be and nuclear power will be competitive in due course; 2. that competitive reactors are now available for construction by 1965; and 3. that reactor power may not become competitive anywhere until the late 1970's. Highlights of reactor testimony:

Philip Sporn, American Electric Power Co.: Sporn, with the help of Walter Zinn of Combustion Engineering, described a new proposal to AEC by the sponsors of a gas-cooled, heavy-water reactor for Florida (*page 29*). In lengthy questioning by JCAE, Sporn said the reactor picture had changed little in the past five years, that reactor technology was moving ahead nicely, and that the utility industry would buy reactors when it makes economic sense to do so.

"I think in our area [chiefly the Ohio valley] the chances of applying atomic energy to the economic and social benefit of our people in the next decade is almost nil. . . . The economics are such that it is not possible to do it.

"On the other hand, I am quite certain that in our area by the year 1980, let us say—that is not so far away because 20 years have a way of going by very fast—by 1980, there will be many parts of the country, I believe, in the U. S. that will find it economically impossible to avoid atomic energy."

Sporn also emphasized that fossil-power technology has presented a "moving target" to nuclear technology, thus tending to reduce the rate at which nuclear power can become competitive. But Sporn said he also thought that "on the whole we have made an excellent record [in reactor technology] and we have made an amazing amount of progress. I think we have a tendency to be more impatient than we need to."

Lyman Fink of General Electric: Probably the most optimistic statement of the hearings came from this GE spokesman: "Industry [presumably GE] is now able to quote large boiling-water reactors for 1965 delivery which are competitive in the highest cost fuel areas. There is strong evidence in the market place that proponents of pressurized-water reactors can make a similar statement." He said two "straightforward" steps were needed "to get atomic power really moving": 1. A progressive continuation of the Commission and industry program for development of fuel and material technology. 2. Up-to-date pricing of enriched uranium.

Fink pointed out that the price of crude U has dropped steadily since 1955 when AEC set its $12/lb price and is now selling in the open market for around $5, or at least $3/lb less than AEC is paying under its

NDA, Olin, Mallinckrodt in merger

NDA and the nuclear-fuel divisions of Olin Mathieson and Mallinckrodt disclosed they were merging into a new integrated firm, United Nuclear Corp., to come into being May 1. For the parent companies of the two subsidiaries involved—Olin Mathieson Chemical Corp. and Mallinckrodt Chemical Works—the move represents a complete sale, and divestment of all except share-owning connections with United; NDA loses its individual identity. Olin will be majority stockholder at the outset in the $25-million new firm. President is William C. Foster, until now a vice president of Olin; vice presidents are John R. Menke, head of NDA; Edward Hartshorne, head of Olin's Nuclear Fuels operation, and Charles D. Harrington, head of Mallinckrodt Nuclear Co. Location of corporate headquarters has not been decided, nor have divisional designations for the facilities of NDA at White Plains and Pawling, N. Y.; of Olin at New Haven and Montville, Conn., and of Mallinckrodt at St. Louis and Hematite, Mo. Olin's nuclear Navy core fabricating work goes to United Nuclear, but operation of AEC's Weldon Springs, Mo., feed materials plant remains with Mallinckrodt Chemical. The new firm will retain the three partners' 1,400 employees.

Barge-mounted reactor bids to be asked again

The Army Corps of Engineers, after months of negotiation with reactor manufacturers and shipyards, has decided to throw out all bids and start over again on its planned 10-Mwe reactor to be mounted on a Liberty ship hull. Because several rounds of bidding had obscured the content of the bids and because of changes in wage scales, the Corps will seek new proposals in a month. Bidders were Alco Products with Todd Shipyards and Geo. G. Sharp; Allis-Chalmers with Sun Shipbuilding; Martin with Maryland Shipbuilding & Drydock; Westinghouse (in separate bids) with Electric Boat, with New York Ship, and with Ingalls.

procurement contracts. He estimated that, at the $5 price, as much as 0.25 mils/kwh could be saved for enriched-U used in boiling reactors, possibly more in others. He disclosed that GE is exploring with AEC—in lieu of reductions in AEC's prices for enriched-U, which he would prefer—the possibility of GE's buying crude U in the market and getting AEC to enrich it for a toll charge.

AEC has been in a position for some time to reduce its price schedules for enriched-U; at the same time, however, it might have to raise its 4% use charge, possibly cancelling out any net reduction. This is one of the reasons AEC has not been able to decide on reductions in its price schedule.

Fink also appealed to AEC to put off expansion of fuels-processing facilities and, instead, store spent power-reactor fuels until private industry has an economic incentive to build reprocessing facilities. "I urge this because additional government investment is likely to postpone further the day when it will become economic to establish privately-owned reprocessing plants."

Kenneth Kasschau of Alco Products, commenting on language in the McKinney report to JCAE last summer, called "refreshing realism" the report's indication that there was little near-term need in the utility field for power reactors. "This does not mean," Kasschau said, "that there is no foreseeable need for atomic energy, but it does indicate that economic competitiveness will not begin to develop in the late '60's, but more likely not before the late '70's. In our opinion, this leads to a significantly different program from one which is geared for economic application in high fuel-cost areas by the late '60's."

Kasschau said the government should proceed with construction of small plants for the military, where there is a current need, and use these plants to improve fuel-element and other technology for large reactors.

Three "public power" advocates—James L. Grahl of the American Public Power Assn., Leo Goodman and Andrew J. Biemiller of the AFL/CIO (Biemiller's testimony was read into the record by an associate in his stead)—renewed a suggestion which has not been so forcefully presented since the 1956 failure of the Gore-Holifield bill: specifically, that AEC undertake a major reactor-construction program to hasten economic nuclear power. Grahl asked that: 1. AEC be given statutory responsibility for developing reactor technology "to the point that private industry can take over," including full responsibility in a new Civilian Nuclear Power div. for technical success of the program; 2. that AEC build and operate the developmental reactors "necessary to advancement of the technology"; and 3. that the co-operative reactor demonstration program be re-evaluated and, possibly, shelved until the utility industry is again ready to co-sponsor and -operate reactors.

AEC had already disclosed in its 202 testimony that it was re-evaluating the cooperative program (*see siting story, at right*), but there seemed little indication that AEC or the new Administration was ready for a major shift in the course of the present over-all reactor approach. In a Feb. 23 message to Congress on natural resources, President Kennedy said the economic nuclear power goal would be pursued just as it has been since 1954—research and development and AEC-industry co-operation on construction of prototype and full-scale reactors. JCAE Chairman Holifield indicated he would follow the Administration's lead.

Goodman and Biemiller: These labor spokesmen indicated they were looking to the new Democratic Administration to revive the essence of the Gore-Holifield program for 8–12 AEC-built reactors. Goodman said specifically that the "basic tenets [of Gore-Holifield] are still valid and it should be updated, reintroduced and enacted." The present program, he argued, "fails to reflect the urgency which our domestic needs and our responsibilities of world leadership demand." He pleaded: "What a tragedy it would be if history were to record that this country developed the atom bomb on a crash basis and then seemed to drag its feet in applying a nuclear science to peaceful purposes."

Biemiller suggested a 4-point program "for full-scale production of nuclear power without further delay": 1. a power demonstration program to be carried out by AEC to produce competitive power in high-cost fuel areas by 1970; 2. immediate conversion of the New Production Reactor, Hanford, to produce 700-Mw of electricity (as well as plutonium); 3. an increase in AEC spending on fusion; and 4. amendment of the 1954 Atomic Energy Act to permit other Federal agencies to participate in nuclear-power development as licensees.

202: Siting Kills Another Project

On March 3, AEC announced abandonment of the Small-Sized Pressurized Water Reactor (SSPWR)—the third reactor project to succumb to siting problems in the last year. The first was the Pt. Loma process-heat reactor (NU, Oct. '60, 23); then, earlier this year, the cities of Los Angeles and Pasadena pulled out of the ICBWR project (Indirect-cycle Boiling-water Reactor) after problems developed there on ultimate construction of 300-Mwe plants (NU, March '61, 24). A fourth project, Southern California Edison's proposed 360-Mwe reactor, is in real site trouble because of Marine Corps opposition to Edison's use of Camp Pendleton.

In spite of the critical siting situation, there was relatively little testimony on siting at the 202's—possibly because, first, there are no easy solutions and, second, because AEC is in the midst of establishing criteria on which industry comments are due in June (NU, March '61, 23).

Mayor Carl T. Sanford of the City of Jamestown (leading contender for the SSPWR) told JCAE that the cost of building the 16.5-Mwe SSPWR at an acceptable, remote site was three times the cost of building it where Jamestown wanted it (in terms of price of the power). He gave this pessimistic—almost bitter—appraisal of the power-reactor picture, based on Jamestown's experience:

"Unless a reactor of this capacity may be safely located within a city of our size, it has no practical value to any electric system and we therefore recommend that it be abandoned in favor of the extremely large reactors which might be located in completely isolated areas and from which transmission lines would not prove to be a prohibitive cost."

New York State's Oliver Townsend, who had been close to the Jamestown negotiations as director of atomic development in the State, devoted his entire statement to siting. The biggest need, he indicated, was a statement from AEC explaining its view on such major siting questions as: Should all reactors be built at remote sites? Townsend said:

"My own reading of the [proposed site] criteria suggests to me, for example, that their adoption would tend to channel future power-reactor development along the line of giant, remotely-located central station plants serving very large integrated grids, whether publicly or privately owned.

"Substantially sidetracked, under the proposed criteria, would appear to be most utility systems where geography or economics dictate a close-in location, including most municipally owned systems. Also substantially sidetracked would appear to be most prospective major ports

of call of the nuclear ship *Savannah*, most major industrial or residential centers that might productively utilize nuclear-produced steam for heating or process purposes, as well as, almost certainly, any demonstration of the large-scale productive value of atomic energy at such conspicuous places as the coming New York World's Fair.

"I do not wish to suggest that the proposed criteria be revised because of such implications. I do think, however, that somehow or other an effort should be made to get these implications, in as accurate form as possible, on the record, so that the public will know what it is getting under the criteria, and consequently will not be unduly disappointed or disillusioned with atomic energy in general because of the effect of the criteria in the immediate years ahead."

Finally, Townsend made the "deliberately provocative" proposal that AEC build the SSPWR or its equivalent at the National Reactor Testing Station and cause it "to undergo the most severe type of accident of which it is capable." He said the results of such an experiment "could be much more meaningful than the paper studies that have been done in the past on the effects of maximum credible incidents. . . ."

202: Nuclear Materials

Nuclear materials development was highlighted throughout the hearings. The Committee adopted a new hearing procedure by opening each day's presentation with a statement on materials development.

R. W. Dayton, Battelle Memorial Institute, gave an analysis of fuel cycle costs in relation to over-all nuclear power costs, finding the former "cannot exceed 1 to 2 mills/kwh if reactors are to be economic." As did many others, he concluded, "If we want to speed the day when nuclear power is widely used, we must accelerate our progress in the materials field by increasing the size of the program. This is not only desirable, but feasible."

In 1980: ALL Power Plants in the Desert?

An intriguing bit of crystal-ball gazing was provided at the 202 hearings by James L. Grahl of American Public Power Assn. Attempting to look further ahead than the usual 10-year forecast, and postulating a complete revolution in the economic organization of the electric power business, Grahl cited projections showing that the U. S. will need to install in the next 10 years as much additional capacity as the total existing in 1959, and three times as much by 1980. This enormous increase in capacity, he predicted, would result in development of a nationwide power transmission system consisting of high-voltage regional grids and extra-high-voltage interregional tie-lines. Thus the future power industry would probably consist of numerous distribution utilities delivering power to retail customers and most getting their power wholesale from regional transmission grids fed by huge automated plants.

"By the time nuclear power becomes competitive," Grahl said, "its principal utilization may well be in large stations of 1-million kw or more capacity, fully automated and tied in with a common-carrier regional grid. Should this be the case, the large nuclear stations probably could feasibly be located in unpopulated areas and require a minimum number of employees, thus greatly simplifying for the large plant the problem of reactor siting."

If this prophecy were eventually to come to pass, it might prove to be an unlooked-for solution to the problem of reactor siting. However, a utility engineering executive said line-losses in any transmission system conceivable today, plus the capital expense of step-up and step-down transformers at either end, would defeat such a scheme as it can be envisaged today. In other words, it would take a technical breakthrough in power transmission to make it conceivable—or economically feasible.

Zalman Shapiro, NUMEC, made a plea for constant funding of research projects through to their conclusion. "There is hardly anything more expensive, more demoralizing, and more wasteful than a research and development program that is turned on and off like a faucet." Shapiro said NUMEC had invested $8-million in plant, equipment, and research in the last four years and would spend at least $1-million more in the next six months.

W. B. Thomas, Zirconium Association, reported on the problem of that industry in gaining wider use in commercial power reactors. The firms now making Zr metal have a capacity of about 6-million lb/yr—twice the anticipated demand from all sources for the next two years, and three times anticipated U. S. needs. In 1960 2,511,000 lb Zr sponge were produced and shipped—4.1% more than in 1959.

George S. Mikhalapov, Brush Beryllium Co., had a similar story to tell about beryllium, whose properties make it useful, he said, for fuel cladding, fuel diluent, flow channels, pressure tubes, moderator canning, moderator, reflector, and core structure. Costs have come down from $250/lb in 1958 for fabricated shapes to $205/lb in 1959, to $170 in 1960; the quality of metal has improved greatly in recent years, he said, and it is now available not only as machined shapes but to a limited extent also as forgings, rolled sheet, tubing and wire. Mikhalapov also asked that the government "support a vigorous program of basic beryllium research."

202: Other Highlights

Frederic de Hoffmann, General Atomic, disclosed that GA is working on application of the TRIGA concept to power units including "for submersible uses for naval defense" and in land-based applications for portable power packs to Mwe." GA is also known to have made a proposal to the Navy last fall for an oceanographic research bathyscaphe powered by a 25–50-kwe Triga-type unit (NU Wk, 27 Oct. '60, 3).

James F. Fairman, Consolidated Edison, wrote the Committee about the Indian Point reactor: "Most of the major construction is now complete and the major items of equipment have been fabricated. . . . The primary system is substantially complete. Most of the equipment is installed in the fuel handling and chemical treatment buildings. . . . The conventional plant is essentially complete. . . . All construction should be complete by November of this year. We expect to make the first fuel loading during that month."

Perry W. Pratt, Pratt & Whitney, spoke of his firm's experience—learned in the Aircraft Nuclear Propulsion program—with lithium cooling. Its excellent heat transfer properties and low vapor pressure permit reducing size and weight of pumps, turbines and piping to ⅙ that of a sodium-cooled system, and results in a small core and small vessel for a given power output. However no material would contain lithium at high temperature until P&W developed a niobium vessel: "Development of a successful lithium-columbium [niobium] system was undoubtedly one of the most important technical breakthroughs in recent years in high-performance reactor technology." Nearly 100 tons or over 90% of the niobium metal produced in this country came out of P&W's ANP effort. Niobium prices have been reduced from $100 to $35–50/lb. A successful pilot niobium alloy industry has been established. The proper application of the lithium-niobium reactor "can result in nearly doubling the output and efficiency of the modern coal-fired steam central power station . . . thermal efficiencies of 50–60% could be achieved," Pratt said.

House Space Committee Explores Nuclear Rocket Outlook

If there was any doubt about the urgency of the U. S. nuclear-rocket program the doubt was pretty much dispelled last month by the people who are manufacturing this country's chemical rockets. Appearing at the most extensive public hearings ever held on the nuclear rocket, witness-upon-witness endorsed an opinion rarely heard up to now outside the nuclear field—that nuclear-rocket propulsion systems must be developed urgently and are, as one witness said, "of tremendous importance to the nation's security."

At hearings called by the House Science and Astronautics Committee the nuclear rocket thus emerged as the natural successor to chemical rockets (*see page 54*) as rocketry goes up the size and power scale to large interplanetary and manned spacecraft. It was brought out that there are three key elements that will determine just how fast the nuclear-rocket program will move: a clearly defined national objective for space exploration, including role of the nuclear rocket; funding to match these goals; and adequate management to insure achievement of the goals.

Although the U. S. is well launched on a space program spread over the next ten years, a re-assessment of the program will be made in the next few months. This will come after Congress has amended the Space Act of 1958 to allow Vice-President Lyndon Johnson to take over the chairmanship of the National Space Council. Under present law, President Kennedy must serve as chairman for this council but he has turned the post over to Johnson, pending Congressional approval.

Then, the Space Council, under Johnson's chairmanship, is expected to take a hard look at the U. S. space program, with Jerome B. Wiesner, President Kennedy's science advisor, participating. Of high priority in the review will be the status of programs to develop large boosters for space use, including the role of nuclear rocketry.

If a decision is made to speed up the development of nuclear rockets, the necessary funding will be requested. This would leave only the question of adequate management of the nuclear-rocket program—the question which had led the House Science and Astronautics Committee to schedule its public hearings.

NASA-AEC Differences

Because of differences between AEC and the National Aeronautics and Space Administration—before Nuclear Rocket Manager Harold B. Finger was given permission in January to issue an invitation for industry proposals to conduct engine-systems development—the Committee wanted a report from AEC, NASA and industry observors on how the joint AEC–NASA Nuclear Propulsion Office under Finger was working out (NU, Oct. '60, 30).

In effect, the Committee asked, Who is in charge? And is he getting proper high-level backing from his superiors at AEC and NASA? Among other things, Harold Finger had wanted NASA's Lewis Laboratory to act as technical monitor for the engine-system contract due to be let to a private contractor after Apr. 3. He was vetoed on this and, instead, is establishing sub-offices of his NPO office in Cleveland, where Lewis is located, and (eventually) in Albuquerque (Los Alamos Scientific Laboratory).

His position on paper, the Committee brought out, is comparable to that of Vice Adm. Hyman Rickover, boss of the nuclear naval program. But, where there is little doubt about Rickover's power—with full Congressional backing—Finger has not acquired this type of authority (he has only been on the job since September). Committee sources have made it clear that they want Finger to get complete cooperation from his agencies and that they want AEC and NASA to work out any administrative differences that might delay nuclear-rocket development. In a move to give Finger higher status, he was promoted by NASA on March 5 to assistant director for nuclear applications to Launch Vehicle Chief Don R. Ostrander—one of four assistants.

Rocket Status

Meanwhile, 1961 is shaping up as the year the nuclear-rocket program took on major status—both in terms of recognition by government and industry and in terms of activities within the program. Finger's NPO received industry studies last month on how flight testing might be carried out (Reactor in Flight Test, or RIFT, studies); studies on major facilities for reactor testing are due later this year; and, long before year-end, an industry contractor should be at work on engine development.

SNAP management transferred; more rocket funds sought

Management of AEC's SNAP program (Systems for Nuclear Auxiliary Power) was transferred last month from Brig. Gen. Irving L. Branch to Col. Jack L. Armstrong. Thus, AEC ended a long period of uncertainty over SNAP management and completed reorganization of its aerospace activities. Last summer, the nuclear rocket was transferred from Branch's jurisdiction, to a new Nuclear Propulsion Office under Harold B. Finger (see this page and NU, Oct. '60, 30). At that time, Armstrong was transferred from his post as deputy to Branch to a new job concerned with advanced reactor concepts. With transfer of SNAP to Armstrong (he retains his advanced-concept responsibility), Branch retains only the nuclear-airplane and -ramjet programs. All three managers—Armstrong, Branch and Finger—report to Reactor Development Director Frank Pittman.

Assignment of SNAP to Armstrong was formally disclosed to the Joint Committee on Atomic Energy on March 13 during a one-day closed hearing on SNAP and the nuclear rocket. JCAE was also told that AEC and the National Aeronautics and Space Administration had requested a total of $20-million in additional funds for the nuclear rocket for fiscal '62 (NASA asking $15-million). The Budget Bureau had turned down NASA's request for $10-million of this but there was a possibility of re-submission. The Bureau was still considering AEC's request for a $5-million boost.

Kennedy expected to decide whether to narrow ANP

The Kennedy Administration was still undecided on a narrowing of the Aircraft Nuclear Program last month, although the Defense dept. indicated it favored the indirect-cycle approach (Pratt & Whitney) over the direct-cycle (General Electric). President Kennedy was expected to make the final decision.

Reactors for Sale: GE, ATL, Kaiser Flourish in Nuclear West

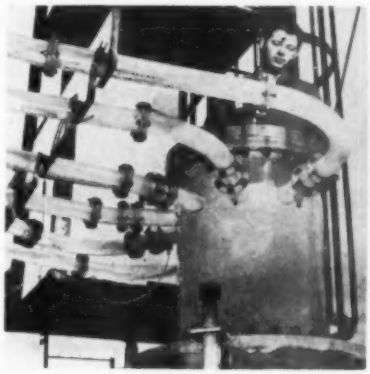
(This is the second of a two-part article on the nuclear industry in the West. The first part appeared in NU, March '61, 27.)

About 22 miles apart below the south end of San Francisco Bay lie the two centers of the vast laboratory-and-production complex that is General Electric's Atomic Power Equipment Department—itself only one of four departments in GE's farflung atomic commitment.

The $22-million San Jose-Vallecitos complex seems to be both vertical and horizontal in organization—and is huge either way. Vertically, it comprises a program of boiling-water reactors and development of components and systems therefor, including nine reactor projects—three already in operation, five under construction, one still in proposal stage. Horizontally, it extends to include research on superheating and on the fast oxide breeder; studies on sodium-graphite, organic, heavy-water and gas-cooled reactors; sale of swimming-pool research reactors; fabrication of both metal (plate) and ceramic (rod) fuel elements; development and sale of nuclear instruments and instrumentation systems, control-rod drives, fuel-handling mechanisms, etc.; sale of irradiation services in pile and hot-cell; applied research on plasma diodes and other thermionic devices for a nuclear direct conversion system, on control-rod materials in various moderators and coolants, on achievement of higher burnups, basic research on ceramics, metallurgy, etc., and on gas-centrifuge separation of heavy isotopes.

Since the firm moved its civilian nuclear headquarters west into a building on the edge of San Jose three years ago, it has filled up six buildings on the 57-acre site, all of them new. At the Vallecitos Atomic Laboratory to the northeast, GE has been running two reactors hard (Vallecitos Boiling Water Reactor and GE Test Reactor); it is about to break ground on a third (Vallecitos Superheat Reactor). It has also just finished moving into a new $1-million chemical and metallurgical laboratory added to the physics, radioactive materials and administration buildings.

San Jose is devoted mostly to administration, manufacturing, and advanced engineering on boiling-water reactors and mechanical components. The latter category includes such facilities as a full-scale test stand for control-rod drives that can be tilted 30° out of the vertical: on this were tested, under simulated seagoing conditions, the rod drives for NS *Savannah*. Under advanced boiling-water development are included: **1.** a mockup of a Humboldt Bay 4 fuel-element section with a nesting cruciform rod, to test the rod drive at operating conditions—1000 psi saturated: the tank is heated by Calrod heaters; **2.** a heat-exchanger test loop for use with superheated steam; **3.** a rig for studying nozzle efficiency and slip in air-water mixtures (little known as compared with steam-water mixtures)—this is part of a basic study on steam separation; **4.** a test facility to study stability and dynamics in boiling water reactor steam loops, to check void distribution and be able to predict slip and voids from pressure loss; **5.** a Dresden reload-core wear test to check fretting corrosion by spacers of new design—a one-year study; **6.** a one-fifth scale model in plastic of the Big Rock Point pressure



vessel (*see photo*), to study flow when all six outlet lines or risers are asymmetrically on one side of the vessel—what kind of baffles are needed? what is the flow in the risers? the riser pressure loss? entrance coefficient into the riser and flow rates in each?

Fuel Manufacturing. Although it may sometimes be lost sight of because GE is so thoroughly identified as an integrated supplier of entire boiling-water reactor plants, the firm is also one of the major factors in the fuel-element business. Both its rod and plate fuel shops are geared for large-scale production; they do a considerable amount of core reload work for research and test reactors the world around (many, but not all, of them GE-built reactors).

Adjoining is a Fuels Development Lab—in reality a small-size production facility—which has two functions: **1.** to learn to make present fuels better, and **2.** to develop advanced fuels. It is now working on advanced fuel for Dresden that, it is hoped, will also help increase considerably the output from that plant (cf. NU, Jan. '61, 25).

Also at San Jose is the nuclear instruments shop, recently set up as a separate unit within APED called Nuclear Electronic Products Section as "an integrated business operation responsible for the development, design, manufacture and marketing of electronic systems and components for the control of nuclear reactors and other specialized instrumentation used in the nuclear field." The move consolidates at San Jose all of GE's nuclear electronics work, some of which previously had been located at the Instrument Dept. in West Lynn, Mass. NEPS now makes some 20 types of nuclear instruments and reactor control systems, plans to add more.

Out at VAL. The Vallecitos Atomic Laboratory, 26 miles and 45 minutes away by auto, is itself divided into two sections: the Lab proper, now under W. Kelly Woods as acting director, and the Irradiation

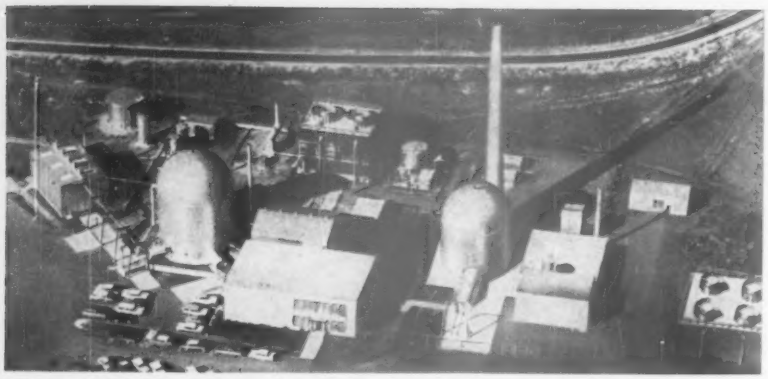
GE and the Great Cladding Debate

One highly-publicized metallurgical problem GE is hard at work on is the great zircaloy-vs-stainless-steel debate, going on since Dresden had trouble with stress-corrosion cracking of some of its zircaloy-2 fuel-rod tubes 15 months ago. GE is now favoring stainless for its next generation of cores, causing acute unhappiness in the zirconium industry.

"We haven't said that zircaloy is no good," says APED's general manager, George White. "It is only that a lot about it is not understood. We are a conservative company, and we cannot afford to sell hundreds of thousands of kilowatts that a customer depends on, and take a chance. It's just a matter of prudence. We have to give warranties.

"We have no intention of abandoning zircaloy. Many in the industry think we're wrong—but no one in the industry has the experience we have had with zircaloy under *these* conditions [of oxide fuel, long exposure, high heat flux, and boiling conditions]. So you can see why we have reservations about plunging ahead on a major station: you have to think twice before you commit $10-million on a core."

A research program on corrosion and hydriding mechanisms in various zirconium alloys is being pushed by APED, and a number of fuel rods of different compositions are in VBWR now. Zircaloy-4 looks promising as an alloy with reduced susceptibility to hydriding.



SOMETHING OLD, SOMETHING NEW: Existing VBWR at left, with artist's impression of new Vallecitos Superheat Reactor superimposed at right

Services Operation under Eugene W. O'Rorke. Under Woods are subsections for physics, metallurgy and ceramics, and chemistry.

Most exciting project at VAL right now is the $8-million VSR, or Vallecitos Superheat Reactor, which GE is designing and building with the New York State utility group ESADA (Empire State Atomic Development Associates). This 12.5-Mwth developmental unit (*see photo*), to be in operation in July 1962, will take saturated steam from the Vallecitos Boiling Water Reactor next to which it will be built, and superheat it to 900–1000° F. It is to be used "as an engineering tool to develop superheat reactor fuel, to examine performance levels under various operating conditions, and to test various superheater concepts including integral and separate superheaters." (For sketches of core design see NU Wk, 5 Jan '61, 3). VSR will be the fifth reactor at Vallecitos, including—besides VBWR and GETR—two smaller reactors: the Nuclear Test Reactor and the Dresden critical assembly, now being used for the control-rod materials study.

GETR is now running at about 50% capacity. It operates on a five-week cycle: one week loading, four weeks in operation. A new heat exchanger has just been added. Major loops working include: a new helium loop to test the graphite-canned fuel and a fission-product trapping system designed by General Atomic for the Peach Bottom High Temperature Gas-cooled Reactor; a water loop for proof-testing the GE-built second core for NS *Savannah;* a new nitrogen loop (the old helium loop, modified) for Aerojet-General's nitrogen-cooled ML-1 truck-mounted reactor (*p.* 29).

VBWR is now operating with a second core that is almost entirely experimental—less than a third of the elements are proven VBWR elements used as drivers. Of 110 elements in the core, 25 (in the center) are for Big Rock Point, 20 for the AEC fuel-cycle program, 15 for outside irradiations for other companies, and one is in the superheat loop. Some Dresden elements left over from the first core, in which the enrichment, the cladding, the spacing of the pins, and the fabrication techniques have been varied, are being run as a high-burnup experiment. Finally, a 10-element section of the core is testing a burst fuel element detector system.

American Standard

Advanced Technology Laboratories division of American Radiator and Standard Sanitary Corp. in Mountain View, south of San Francisco, has been in the nuclear field for four years. Its primary aims are to develop proprietary reactor systems ("we don't want to be a 'me too' in this business") and to bid on invitations on established types of small and medium-size reactors. ATL bid on both AEC's Small-Size Pressurized Water Reactor and its low-temperature process-heat reactor. ATL also bids on components—reactor vessels, heat exchangers, valves, etc.—for which it has the manufacturing capability of the big American Standard organization as backup. (For example, the firm's Detroit Control division did the process instrumentation for Shippingport, using a mag-amp system.

ATL's work is primary in two areas: fuel-cycle development, and development of two advanced reactor concepts—Variable Moderator Reactor and mercury-cooled fast breeder.

Fuels work—some of it for Euratom—has included development of a uranium dioxide flat plate coated with zircaloy by a plasma spray method; a cold extruded zircaloy tube method to eliminate surface cracking and increase yield; studies on thermal stress fatigue of zirconium, on a thorium-uranium alloy with improved tensile strength at high temperatures, and on uranium metal of improved radiation stability.

The VMR with its complete separation of liquid moderator and liquid coolant would permit any combination or permutation of light water, heavy water and organic, in either role. Eliminating as it does all control rods (control being accomplished by raising or lowering the moderator level), it is a natural for superheater reactors in that it does away with the need for developing high-temperature control rods; it also permits a much smaller reactor vessel. ATL has completed a 20-Mwe design for AEC, and hopes to sell a VMR plant to AEC or a utility.

The attractiveness of the mercury fast breeder lies in its prospectively low capital cost and high efficiency. At 1000° F mercury coolant (which has been used in mercury turbines for 20 years), 40% thermal efficiency is obtained, ATL says; going to 1300° F makes possible 45–50%. Low alloy steels may be used, intermediate heat exchangers and sodium problems are eliminated (mercury vapor hazard is said to be entirely a thing of the past). A study of a 100-Mwe plant indicated 20–30% lower capital cost than Fermi. A variant of this reactor that ATL is even more enthusiastic about is the mercury-cooled fast breeder fueled with thorium.

ATL has been successful also with its Argonaut-type research reactor, UTR-10, of which it has sold units to Virginia Polytechnic, Iowa State, and in Australia and Japan; three have been shown in AEC traveling exhibits.

Kaiser Engineers

The other major West Coast architect-engineering firm in the nuclear field (besides Bechtel: NU, March '61, 28) is Kaiser Engineers, in Oakland. Designer and builder of AEC's Engineering Test Reactor at the National Reactor Testing Station, Kaiser is now finishing up design of the Experimental Gas-Cooled Reactor at Oak Ridge (design is now 99% completed). Kaiser is also engineer-constructor for the Hanford New Production Reactor (with Burns & Roe as architect-engineer).

Kaiser has just finished a cost-evaluation study for AEC of nuclear superheat power plants, taking designs of various manufacturers for nine different 300-Mwe steam-cooled reactors operable by 1967 and putting them on a common basis. Kaiser is also consulting on the Antarctic reactors and Vietnam's research reactor, is doing design for Westinghouse of 44- and 400-Mwe nuclear plants using integral boiling superheat reactors, and for AEC has just done a nuclear power cost reference handbook and is doing cost evaluation of AEC's 10-year program reactors.

RDI: Has it 'Arrived' as a Supplier of Radiation Machines?

Kennard H. Morganstern, president of Radiation Dynamics, Inc., Westbury, L. I., is sitting on something of a powder keg: RDI's common stock has been selling in recent weeks for as much as $90/share although the company has yet to show a profit. Moreover, RDI has delivered only one particle accelerator (its basic product) since it began marketing its radiation machines early last year and, until this and subsequent RDI-delivered machines build a history of operation, the company's approach to machine design remains unproved.

Nevertheless, there is no perceivable gloom, or even doubt, in Westbury. Any tendency in this direction appears to have been simply overwhelmed by Morganstern's personal dynamism, by an unshakeable faith in the company's product, and by the excitement of the radiation-machine business itself. In the nuclear field, nothing seems to have quite the unfettered potential in research, medicine and industry as do particle accelerators.

RDI began marketing its line of Dynamitron machines in January, 1960, after an 18-month period of prototype development—August, 1958 to December, 1959. In the fifteen months since, the company has gained an extraordinary momentum:

- Six electron and/or positive-ion Dynamitrons have been ordered by government and private research organizations in the U. S. and Japan, and single orders have been received for a 1.2-Mev positive-ion power source (to Brookhaven) and a duoplasmatron ion source. The company is on two-shift operation to get these machines delivered by June.
- A radiation service center has been established at RDI headquarters, where the company recently began conveyor-line sterilization of disposable hospital supplies for a Pennsylvania firm (NU, Jan. '61, 28) and, as of late February, has an order to irradiate one million feet of a new plastic wire for the U. S. Air Force.
- Sales agreements for the marketing of RDI products abroad have been signed with C. Itoh Co. (for Japan) and Westrex Corp., a division of Litton Industries (for Western Europe). Under discussion is an agreement with Vickers Research, Ltd., for marketing of RDI machines in the British Commonwealth (except Canada). And, in a particularly significant overseas development, RDI has completed negotiations with France's Adany Research Laboratories for construction this year of a radiation-machine service center at Adany's headquarters near Paris. Adany would provide site and housing and RDI and its European sales representative, Westrex, would supply a 1.5-Mev electron or positive-ion machine.

Earlier, RDI had worked out an agreement with Wilmot-Castle, Inc., Rochester, N. Y.—a supplier to the medical field—for installation of a service machine in Rochester. Wilmot-Castle, which represents RDI in radiation sterilization (exclusive of food), would operate the machine as part of a sterilization center.

- RDI, in February, won a $60,000 contract from the Air Force to investigate intense ion-source beams, under the AF's electrical-propulsion program for spacecraft. The contract has a dual significance: it marks RDI's abandonment of a policy to avoid government contracts (the company is now going all out for research-development contracts); and it fits into the firm's plans to develop electrical-propulsion equipment for space.
- In a step toward another company goal—the supply of equipment accessory to its machines—RDI was negotiating last month with a French firm to market the latter's mass spectrometer in the U. S. This is the first of a series of arrangements RDI hopes to negotiate with foreign and U. S. firms to provide a product line complementary to its machines.
- Earlier this year, RDI began creation of its own U. S. sales force by taking on a salesman for the mid-West; during 1960, the company was marketing through sales representatives and direct advertising.
- Also earlier this year, the company submitted its first offer to supply its largest accelerator—a 6-Mev positive ion machine (essentially a tandem 3-Mev machine) to cost about $400,000. The machines heretofore available have been electron, positive-ion or combination units in the energy range 0.5–3 Mev (5–30 kw).
- RDI has begun negotiation for lease later this year of a new building to go up near its present headquarters—a 30,000-sq-ft plant to include a machine-testing vault. The new building would eventually reach 100,000 sq ft, in increments of 30–40,000 ft as needed. A second vault at the present site, which has been reserved for testing of machines now on order, would be released for service irradiation when the new vault is ready.

COFOUNDERS OF RADIATION DYNAMICS, Marshall Cleland (left) and Kennard Morganstern, teamed up in 1958. Cleland invented RDI's radiation-machine concept; Morganstern raised the initial capital and manages the company as president

Morganstern Joins Cleland

RDI was founded in June of 1958, almost by chance. Marshall R. Cleland, inventor of the Dynamitron (NU, Aug. '60, 52), had formed his own company in St. Louis, in 1953, to develop his idea for a high-voltage particle accelerator. For almost five years, Cleland worked on his idea. In the spring of 1958, he went East to raise money to permit him to continue (he had reached 1 Mev, 2 milliamps with his prototype).

Meanwhile, Morganstern, vice-president of Nuclear Corp. of America, had just completed a survey of cobalt-60 irradiation of a rubber-coated wire for the Anaconda Wire & Cable Co. He decided there was a future for radiation—but not so much for cobalt-60 as for accelerators. Morganstern undertook to raise funds for Cleland's company from wealthy friends; when they said they would go along, if Morganstern joined the venture, he took the plunge. In June, RDI was incorporated, Morganstern having raised $300,000, and RDI moved into its present quarters in August.

Since that date 2½ years ago, the firm's employment has doubled every six months to the present total of about 70. The company booked $660,000 in orders in 1960 (first marketing year) and predicts sales of $1.5-million this year (including most of the business booked last year). Sales goal next year is $2.5-million.

In a burst of optimism characteristic of Morganstern, he has told New York security analysts that he expects to double the rate of growth of High Voltage Engineering Corp., world's largest supplier of radiation machines (NU, Jan. '62, 22). He expects RDI to reach in six years "what it took High Voltage 12 years to do"; by

1965, Morganstern predicts, RDI sales will reach $10-million annually. HVEC reported sales of $12.3-million in 1960, including all subsidiaries.

RDI has met HVEC in direct competition several times in the last year and Morganstern asserts that several Dynamitrons were sold to customers who had specified Van de Graaff machines in their bid invitations. Dynamitrons were ordered in these cases, Morganstern contends, because of their high-power potential (the 1-Mev machines are rated at 10 kw, the 3-Mev units at 30 kw); although the customer may have had no requirement for the power when he ordered, he points out, the idea of having the power available is attractive.

Timing Crucial

Morganstern feels that the timing of RDI's entry into the accelerator field, with its high-power machines, has been particularly fortunate. It came at a time, he notes, when the demand for accelerators in research was high (chiefly because of the U. S. outer-space program) and before HVEC had perfected several high-powered machines it has had under development. He feels RDI has filled a "gap" that might have been filled this year or next by HVEC's Insulating Core Transformer or comparable machines (NU, Aug. '60, 54). "So we have had an opportunity to get entrenched" in the field before the gap was closed, Morganstern declares.

The RDI official considers the Dynamitron and Van de Graaff directly competitive in the nuclear-physics area; in the competition to supply electron machines for industrial processing, he feels RDI's competitors are General Electric (resonant transformer), HVEC (its high-power machines) and, potentially, firms like Varian Associates and Hughes Aircraft who have high-power radiation machines in development.

His estimate of the need and utilization of radiation sources in industry is this: for processes requiring sources of up to 1-kw, radionuclides will be most economic; in the range 18–50 kw, machines will be used (he sees little industrial need for sources of more than 50 kw because of the relatively few products marketed at the rate equivalent to 50 kw of power—40,000 megarad lb/hr of product or 30 million lb/yr at 1-million rads).

RDI has recently raised $700,000 in expansion capital to bring its total investment in radiation to almost $1.5-million. This investment will automatically "pay off" if and when RDI achieves a private goal of Morganstern's: acceptance of "Dynamitron" as a generic word as HVEC's "Van de Graaff" trademark has been accepted.

Britain: Problems at Dounreay, AGR; Novel Vessels

Two of Britain's advanced reactors were taking it on the chin last month. At Dounreay, the experimental fast breeder was suffering from an ailment called "vortex entrainment"—a type of hydrodynamic instability in the coolant—that was threatening to delay full-power operation by up to a year. And at Windscale, a new problem was threatening to cast a shadow over the Advanced Gas-cooled Reactor prototype.

Meanwhile British engineers, undaunted, are planning to propose a daring nuclear engineering innovation —a concrete pressure vessel for one of the next large civil stations. So far only the French have gone in for such large concrete vessels.

Dounreay Troubles

Dounreay's problems were spotlighted when they erupted into the London press and brought forth a prompt, official Atomic Energy Authority denial that the reactor would be closed down: the troubles being experienced were part and parcel of the object of the experiment, which is to illuminate problem areas. Beyond that AEA would say very little.

The vortex entrainment phenomenon is crudely analogous to bathtub hydrodynamics: when the plug is pulled with the water-level well down in the tub, a strong vortex is generated and air is entrained (gurgling noises); but when the tub is full there is little evidence of any circulation at the surface and no entrainment. In the Dounreay reactor nitrogen cover gas is used in the reactor vessel above the sodium pool. Nitrogen is sucked down into the 24 outlet nozzles; this not only interrupts the motor action of the electromagnetic cooling pumps and causes short-time loss of coolant, resulting in a flow instability; the presence of gas in the pumps causes mechanical damage as it distorts the eddy-current field which mechanically deforms the tube wall through the pump and constricts flow. It's believed the condition arises only when coolant flow approaches about 75% of maximum flow. Therefore the reactor has been restricted to low power output, probably less than 1 Mw. (It is rated at 72 Mwth, 15 Mwe.)

U. S. sodium-cooled reactors have escaped the problem by designing for a high head of sodium above the nozzle: the Sodium Reactor Experiment has a 5-ft deep sodium pool above the nozzle, Fermi has 6–7 ft, whereas Dounreay is understood to have only 2–3 in. suction below the surface of the sodium pool to the top of the nozzle.

The solution believed now to be under investigation involves raising the height of the coolant above the outlet. If this fails, all alternative solutions will involve extensive redesign lasting at least a year.

AGR Problem

Uncertainty also surrounds the AGR reactor at Windscale, now several months behind schedule due to fuel cladding (in beryllium) problems. In addition researchers of the Central Electricity Generating Board suspect that the reaction between carbon dioxide coolant and graphite at higher temperatures is more serious than originally predicted and could affect the feasibility of the project. (In this reaction, the coolant attacks the graphite moderator, forming carbon monoxide and free carbon: the latter is carried around in the primary loop and deposited in the cold leg, thus eventually blocking circulation.) Graphite–carbon dioxide compatibility is one of the major research tasks to be undertaken at CEGB's new laboratory at Berkeley, scheduled to be formally opened May 29.

Finally, beryllium is reported to "become distinctly unhappy" in contact with uranium oxide at temperatures of about 1100° F.

Opposition to further development of AGR is mounting, on the ground that the special problems it generates are not commensurate with its advantages over the Calder-type stations. U. K. policy now seems to favor development of the Calder type until 1970, when it will be superseded directly by the High Temperature Gas Cooled system (originally the third step, following the Calder and AGR types.) For the time being even Wylfa—the ninth British civil station—is now seen likely to be a Calder type; whereas earlier, Sizewell or Oldbury—the seventh and eighth—were expected to be the first commercial-size AGR type.

Concrete Vessels

Very serious consideration is being given, it's understood, to use of reinforced-concrete pressure vessels at Oldbury or Wylfa nuclear power stations. Atomic Power Constructions Ltd., one of the strongest advocates of concrete, is sticking to spherical steel vessels in its proposal for Oldbury, and switching to concrete for the subsequent Wylfa design. Nuclear Power Group will propose a concrete cylinder for Oldbury and Wylfa both—possibly a pressurized concrete structure in which both a steel reactor vessel and the heat exchangers would be placed.

REACTOR NEWS

AI DESIGNING 1–3-Mwe SNAP-4

First glimpse at the classified SNAP-4 reactor was offered by Chauncey Starr, president of Atomics International at the 202 hearings (*see p. 21*). SNAP-4, he disclosed, is a 1–3-Mwe scaleup of the smaller SNAP (Systems for Nuclear Auxiliary Power) reactors—putting it in the package power category. Like the 3-kwe SNAP-2 and the 30-kwe SNAP-8, SNAP-4 is fueled and moderated with solid rods of uranium hydride mixed with zirconium hydride, and controlled by movable beryllium reflector blocks and rotating drums. Unlike them, it will be steam- instead of mercury-cooled. But SNAP-4 "is not just another boiling water reactor," Starr told JCAE: in it moderation is performed 70% by the hydrogen in the hydride fuel alloy, resulting in 6–10 times greater power density. SNAP-4 will weigh about 17 tons and would be contained in a cylinder 16 ft long and 7 ft dia. It thus offers an easily-transportable, factory-assembled and -tested terrestrial power unit. Primary motivation for the project at present is for the Navy, for underwater application—Starr spoke of a 35-ton containment pressure vessel required to house a unit at 2000 fathoms' depth. It could produce about 3000 shaft horsepower. In the civilian field, AI feels, SNAP-4 would meet an industry need for compact, reliable power for special applications (example: in mining installations in remote areas) even at premium prices.

ICECAP REACTOR COMPLETES TEST RUN

Camp Century's PM-2A reactor, under the Greenland icecap, successfully completed its 400-hr test last month. The pressurized-water reactor ran at camp load of 750 kwe (full power is 1500 kwe). The test began Feb. 10 after added shielding was installed (NU, Feb. '61, 25).

NEW FUEL MAKER: UNIVERSAL MATCH

Universal Match Co. of St. Louis is attempting to break into the ranks of fuel elements fabricators. The firm started looking at nuclear fuel two years ago, at the suggestion of its neighbor, Mallinckrodt Nuclear, whose UO_2 pellets it loaded into aluminum or zircaloy tubes and sealed the end closures. Universal Match has made fuel for several critical experiments, and has installed a pilot plant set-up. Its first bid for a prime contract to supply an entire core for a major power reactor was (unsuccessful) for Sioux Falls; it has bid on the Experimental Gas-Cooled Reactor job for Oak Ridge.

ML-1 REACTOR DELIVERED TO IDAHO

An Army semi-trailer truck delivered the Mobile Low-power reactor No. 1 to its test building at the National Reactor Testing Station from Aerojet-General's Downey, Calif., fabrication plant. The 500-kwe nitrogen-cooled, light-water-moderated unit will become the world's first closed-cycle gas-cooled nuclear power plant (NU, March '60, 28). Pre-startup testing of the reactor, followed by low-power operation, are to begin at once; the turbine unit is scheduled to be delivered in midsummer.

PLEA IN JCAE FOR HOMOGENEOUS SYSTEM

An eloquent appeal for keeping alive the U. S. homogeneous reactor program was made in the 202 hearings by its chief champion, Alvin M. Weinberg, director of Oak Ridge National Laboratory. The entire program is presently scheduled to be closed down June 30 (NU, March '61, 31). Weinberg's chief argument is that achievement of either practical breeding or practical fusion would permanently solve man's energy problem, but "whereas we are in my opinion far from a solution of the fusion problem we are reasonably close to a practical solution of the breeder problem. . . . Within 10 to 15 years one can have a thorium breeder system that is at least as economical as other reactor types now being worked on seriously." He cited present stable operation of Oak Ridge's Homogeneous Reactor Experiment No. 2 as "evidence . . . that the problem of fuel stability has been solved," and revealed "an important success in circulating, for the first time inside a reactor, a slurry of thoria in heavy water. The loop operated without incident for 2220 hr. As a result we are confident that the blanket problem can be solved. . . My belief is that unless we hit a streak of very bad luck. . . we could be ready to start designing a small aqueous homogeneous breeder in about two years." Therefore, he concluded, it makes no sense not to be able to afford $2-million/yr to keep homogeneous technology alive when we—properly—spend $25-million/yr on fusion. Moreover the fused salt system—in favor of which AEC said it was phasing out the homogeneous—should not be considered an alternative: it is "not as good a breeder . . . Our economic studies do not indicate that it has any substantial merit compared to the AHR, and we have not yet run a fused salt reactor for a long time. On this basis I simply do not think it is a very good idea to junk this one [homogeneous] in favor of the other one." Weinberg also confirmed that ORNL has had to terminate 115 employees, 50 of them technical ones, and will have to fire 85–110 more. Affected, besides homogeneous, is chemical reprocessing pilot plant work.

GE SEEKS SUPERHEAT REACTOR PERMIT

General Electric has applied for a construction permit for VSR—the Vallecitos Superheat Reactor, to be built alongside the Vallecitos Boiling Water Reactor (NU, Jan. '60, 20; photo this issue, p. 26). The application covered initial operation of the $8-million reactor at 12.5-Mwth. GE, building it for ESADA—Empire State Atomic Development Associates—has already ordered an 80-ton pressure vessel from Nooter Corp., St. Louis.

NEW PROPOSAL ON FLORIDA REACTOR

Florida West Coast Nuclear Group and East Central Nuclear Group, partners on the Florida pressure-tube gas-cooled reactor project, have offered AEC a new basis for continuing the partly-stymied program (NU, Sept. '60, 25). The partners have concluded it was a diversion of effort to go through with the originally-planned, transitional stainless-clad first core, preferable to concentrate immediately on the ultimate, beryllium-clad, core, with a research effort on Be. Meanwhile Combustion Engineering, asked for a fixed-price proposal on the 50-Mwe pilot reactor, did not include a price on the first core nor any guarantee on fuel cost or core performance; total price was substantially higher than previous ECNG estimates. Consequently FWCNG-ECNG said they could not make a firm commitment to AEC to build the pilot reactor, proposed instead that research-development continue to end-1962, with estimated costs of $5.49-million to be shared equally by them and AEC. ECNG would report on feasibility of the proposed reactor by Oct. 31, 1962; AEC would review and decide by Dec. 31, 1962 whether or not to agree. If AEC finds the plant feasible, either FWCNG builds plant—with $11-million contribution from ECNG plus reimbursement by AEC of ECNG's 1961–2 matching research contribution; or the utilities refund to AEC its research contributions. If AEC decides the project is technically infeasible, it would be terminated.

WORLD NEWS

Euratom Pushing ESSOR Design

Euratom has now signed two contracts for detailed preliminary design of ESSOR, the experimental reactor for ORGEL—Euratom's organic reactor project (NU, March '61, 32). The contracts are 1. with France's Groupement Atomique Alsacienne Atlantique (a consortium of Société Alsacienne de Constructions Mécaniques and Chantiers de l'Atlantique) teamed with Interatom of Germany (joint subsidiary of Demag and Atomics International); and 2. with France's Indatom teamed with Belgonucléaire and Germany's Siemens. The designs are due in June, when Euratom will select one for further detailed study. The 50-Mwth ESSOR—natural-uranium-fueled, heavy-water moderated and organic-cooled—is designed for flexible operation over a wide experimental range. It will probably be built at Ispra. Euratom is committing $6-million this year for ORGEL research, and already has 14 contracts placed in Europe on this project.

Isotope Bureau for Euratom

Euratom will establish its own Isotope Bureau, a joint meeting of the Euratom Commission, isotope producers and instrumentation manufacturers decided. Concurrently Euratom will initiate a policy of placing research and development contracts with private firms and mount an intensive campaign to encourage isotope use. The Commission expects a major development in industrial and agricultural use of isotopes once information is made available through the new Bureau; thirty information pamphlets, dealing with specific industries, are already planned. The six Euratom countries have some 2,400 users of isotopes. Half of them are medical, taking about 70% of individual consignments; the remaining 1,200 are industrial users, largely in Germany. Production of isotopes has not been sufficient; imports come mostly from Britain, especially high-intensity types for sterilization and chemical processing. However production within Euratom will increase shortly.

U. K. AEA Reorganized; New Reactor Group

A Reactor Group, a new fifth major division of Britain's Atomic Energy Authority, has been split off from two existing groups and will carry responsibility for designing and developing reactors. The present Development and Engineering Group at Risley, which designed Calder Hall and the Advanced Gas-cooled Reactor, has been renamed Reactor Group, and will also take over the Winfrith Research Establishment, transferred from the Research Group. The Development and Engineering Group's existing responsibilities for design and construction of plant, works and buildings will be transferred to a new Engineering Group, which will also take over Production Group's responsibilities for design and inspection of production fuel elements. The Research Group continues unchanged except for transfer of Winfrith; the Weapons Group is unaffected. AEA also set up a new Deputy Chairman post to assure technical and scientific coordination throughout the Authority. Sir William Penney, member for Scientific Research, will be its first occupant. Sir William Cook, member for Development and Engineering, becomes member for Reactors. Sir Leonard Owen becomes member for Engineering as well as for Production. New group heads, titled managing directors, are F. A. Vick, Research (he remains also director of Harwell); R. V. Moore, Reactors; J. B. W. Cunningham, Engineering; J. C. C. Stewart, Production.

Two New Reactors in France

Two new special-purpose reactors of novel design are about to enter construction phase in France: Siloë, a 10-Mwth pool for Grenoble, and Pégase, a 30-Mwth pool for fuel-element loop-testing, at Cadarache. Siloë, a 10^{14} flux unit costing $2.5-million, will be built, in 18 months, by Indatom. It is ten times more powerful than Mélusine, Grenoble's 1.2-Mwth pool operating since March 1959. Its core design is very similar, however: fuel elements, control rods and rod drives are standardized. To cut down local activity at the pool surface, hot filtered water will be injected at the surface to create a downward-forced-convection current (a similar system is used in some U. S.-built pool reactors: NU, Jan. '61, p. 84). Pégase, an $8-million facility, will be designed for just one purpose: testing fuel for France's future gas-cooled power reactors, yet it will be quite flexible. Eight independent gas-cooled test loops will lie around the core like unattached spokes around the hub of a wheel. Each loop will have its own blower, heat exchanger and gas cooling circuit for the fuel rod under test—all submerged in the pool. Thus loops may be designed to simulate operating conditions in different reactors; in the first set of loops, for example, four will operate at 355 psi and four at 850 psi to test fuel rods for EDF-2 at Chinon and EL-4 in Brittany, respectively. The loops can handle 125 kw each. Each will be mounted so it can slide radially toward or away from the core, to vary flux in the fuel rod under test—from 3×10^{13} to 10^{14}. Further, the pool is deep enough at 39 ft so that a test loop can be lifted clear and trundled out of the irradiation pool, underwater, to an adjacent cooling pond without interrupting tests in other loops. Pégase is to be completed in late 1962; a prototype core assembly, Peggy, started up in February.

Russian Power Reactor Delayed One Year

A year's delay in completion of Russia's first large-scale all-power reactor is indicated by a recent Moscow news article. Whereas the Russians had talked of 1961 completion for their 210-Mwe pressurized water reactor at Novovoronezh (= New Voronezh, a suburb of Voronezh), a Tass article says the first section of the two-reactor station "is to go into operation next year." (Each section will consist of one 210-Mwe reactor feeding three 70-Mw turbines.)

NPD Behind Schedule

Canada's first power reactor, the 20-Mwe Nuclear Power Demonstration reactor, is some seven months behind schedule, not yet having gotten delivery of its reactor vessel. The fabricator, Canadian General Electric, apparently ran into aluminum welding problems, but now expects to deliver the vessel for the heavy water pressure-tube reactor by end-April—seven months late. Atomic Energy of Canada Ltd. expects to achieve criticality this summer, "but we're not really striving to make criticality a date"; as for full power, "we expect to squeak in toward the end of the year." AECL's 1959–60 annual report had said, "The plant should be nearing completion at the end of 1960, should be at full power by mid-1961."

Damy de Souza Brazil's New Atom Chief

Prof. Marcelo Damy de Souza Santos, long Brazil's foremost nuclear researcher and director of the Atomic Energy Institute at the Univ. of São Paulo, has been named by Brazil's new President, Janio Quadros, to succeed Adm. Octacilio da Cunha as head of Brazil's AEC.

NEWS IN BRIEF

Seaborg Confirmed; Haworth Fifth AEC Commissioner

After 36 minutes of questioning Feb. 23, the Joint Committee on Atomic Energy unanimously recommended Glenn T. Seaborg for chairman of AEC. The next day the Senate confirmed the appointment and Pres. Kennedy immediately designated him chairman (NU, Feb. '61, 24). Early the next week, Leland J. Haworth, director of Brookhaven National Laboratory, was nominated to fill the last available Commission seat. The two appointments brought to three the number of technically-trained men on the Commission–the highest number since its inception: a chemist, Seaborg; a chemical engineer-industrialist, Robert E. Wilson; a physicist, Haworth, and two lawyers, John S. Graham, and Loren K. Olson.

Seaborg

Haworth

Comments on Seaborg's appointment included: he should be an easy man to work with, should be able to handle the administrative duties because of his experience as Chancellor of the Univ. of Calif., and that as the first scientific-chairman he might stress research-development projects, and place more work in the hands of his fellow Commissioners. A long-time colleague of Seaborg described him as cautious, quiet, a good planner, relaxed, one who does not say more than he must and who will work well not only with other government officials but also with the other commissoners.

Haworth, who has been a leader at Brookhaven since its establishment in 1947, is a nuclear physicist and an authority on design of high-energy accelerators. In December he had been named president of Associated Universities, Inc., the group of Eastern universities operating Brookhaven.

Meanwhile, JCAE got a new vice-chairman, Sen. John O. Pastore (D-R. I.) although Sen. Clinton P. Anderson (D-N. M.), as senior Senate member, was slated for the post when he relinquished the chair to Rep. Chet Holifield (D-Cal.), making Sen. Pastore next in line for the chairmanship in 1963.

Wilson Takes Strong Stand on Radiation Development

In a speech before Pittsburgh industry officials Feb. 27, AEC Commissioner Robert E. Wilson spoke about the unlimited potential for uses of radioisotopes in industry. He urged strongly that industry seek out new techniques that would harness for wider applications available radiation sources. "Because new technology is expensive and difficult to obtain, private research and development is often not feasible," he said. "Therefore, it becomes the responsibility of the AEC to aid in developing the application of this energy resource to the point of widespread technical and practical feasibility."

Continuing, he warned: "There may be too much satisfaction with present achievement of radioisotopes on the part of many users and a lack of vision as to their potential . . . . we must reject the concept of resting on our laurels, assuming that we have reached the summit. We must consider ourselves rather as being at the threshold of the frontier of new and dynamic advances in radioisotope and radiation techniques . . . . this threshold will not be crossed without the productive teamwork and interplay of science, industry and government."

Commissioner Wilson's remarks on the importance of radiation constituted the strongest public statement by a member of the Commission on this since Willard F. Libby left AEC in 1958.

Workers Compensation Act May Come Up This Spring

Hearings on a proposed Radiation Workers Compensation Act may be scheduled by the House Education and Labor Committee this spring. The appropriate subcommittee must schedule hearings early, an informed Washington official said, if hearings are to be held at all this year.

Both Rep. Herbert Zelenko (D-N. Y.) and Rep. Melvin Price (D-Ill.) are sponsoring identical bills to one introduced by Zelenko as Congress adjourned last year. In February, Committee Chairman Adam Clayton Powell (D-N. Y.) had said he would schedule hearings as soon as President Kennedy's aid-to-education program is out of the way (first subcommittee hearings started March 15). In the "202" hearings, AFL-CIO Andrew J. Biemiller said the compensation bill had been drafted by AFL-CIO, and he urged quick action.

Indemnity Proposed for Space, Remote Reactors

Martin's Co.'s Clark C. Vogel proposed at the "202" hearings that indemnity be established against nuclear damage abroad from reactors used in the space program. He said: "My purpose . . . is to suggest that the Committee might wish to consider the problem of indemnity in two very important fields, i.e. indemnity against liability for a nuclear incident causing damage to persons and property outside the U. S. as a result of 1. utilizing nuclear energy in space or 2. the installation and operation of a nuclear power plants or other devices utilizing atomic energy at U. S. government installation beyond our national boundaries." Vogel also pointed out that the Price-Anderson indemnity measure excluded coverage outside the U. S. His suggestion was sympathetically received by JCAE. Sen. Clinton P. Anderson (D-N. M.) asked Vogel to send "some language" on the subject. Alco Products and General Electric also asked for action on this matter.

AEC Approves Internal Regulatory Reorganization

The changes proposed in a study of AEC's organizational structure (NU, March '61, 26) have been approved by AEC. When put into effect, AEC's regulatory and promotional functions will be separated at the staff level. A new office will be established, Director of Regulation, to report directly to the Commissioners.

GE Asks AEC to Reconsider Gas-centrifuge Secrecy

General Electric has asked AEC to reconsider the classification of gas-centrifuge technology and the proposed access-permit program in this field (NU, Feb. '61, 27). GE's comments were the strongest of only seven filed in February by industry organizations. "In the U. S.," GE pointed out, "the process is the principal hope for disentangling civilian from military production of fissionable material, and for early establishment of a competitive economy in nuclear fuels. Classification in the U. S. will materially retard progress . . . by slowing down private investment and exchange of technical information." GE acknowledged the weapons aspects of gas-centrifuge isotope separation but noted that other means of developing weapons material were available to those countries wishing to do so.

RADIATION NEWS

New Irradiated Wire; Polaris Needs 2nd Supplier

In two significant developments in the market for irradiated plastic wire last month:

1. Radiation Dynamics, Inc., disclosed it has received an order from an undisclosed private firm for electron-processing of one million feet of plastic wire. The irradiated wire is for use by the Air Force. Its acceptance by the AF marks the second such approval of irradiated wire, on a large scale basis, by the military. The first was irradiated-polyolefin wire for the Polaris missile.

2. Lockheed Aircraft Corp., which accepted irradiated wire for Polaris ten months ago (NU, Aug. '60, 27), disclosed that it was still looking last month for a second supplier of the wire. Original supplier is Raychem Corp. Lockheed said it was buying the wire at the rate of $75,000–$1,000,000 annually and that it felt it was "in a hell of a position with a single source." Several firms were scrambling for the second-source spot, including Suprenant Co., Boston, Sequoia div. of Anaconda Wire & Cable, Hi-Temp Wires, Inc., and Radiation Materials, Inc., newly-formed joint venture of Radiation Applications, Inc., and Loral Electronics Corp. (NU, Jan. '61, 28).

Pofcher Asks for More Spending on Radiation

The lone radiation-industry witness as this year's "202" hearings of the Joint Committee on Atomic Energy was Munroe Pofcher, president of Radiation Applications, Inc. (*note above*). He asked JCAE to support increased spending on radiation research, particularly radiation chemistry; to support construction by AEC of demonstration radionuclude irradiators, specifically a beta irradiator; and to consider holding public hearings on industrial uses of radiation to focus attention on the importance of radiation economically.

Generally, Pofcher's suggestions were given a hostile reception by JCAE members. However, their questions also indicated that the Committee has not followed the industrial-radiation situation as closely as it has nuclear power and the use of radiation in the life sciences. For example, Pofcher's plea for increased fundamental and developmental research in radiation chemistry—a development area requiring substantial dollar outlays—was met with the argument that industry was already making profitable use of isotopes in such applications as radiation guaging—a relatively low-investment technology.

"We are really only at the beginning of the threshold of understanding mechanisms of radiation, how to bring radiation costs down, how to make it competitive with other processes, or not competitive with other processes so much as how to make it competitive in terms of being useful for new processes," Pofcher testified.

"The whole theory of the field is still, as is the case with nuclear power, very much in its infancy. And this kind of long-range research and development is not the kind of thing that private industry can do alone. This, I think, is the reason that you are helping support research and development in the power [reactor] field. And what I am saying is that the same reasons are applicable [in radiation chemistry]."

Contractor Selected for Two Food Irradiators

AEC expects to assign its second and third cobalt-60 irradiators under the Civilian Food Irradiation Program to the Universities of California, Davis, and the Washington, Seattle. This came out last month as AEC announced it had given a $58,383 contract for the units to Process Equipment Corp., Lodi, N. J., for delivery to the two West Coast sites by June; Brookhaven National Laboratory will provide 30,000 curies of cobalt for each irradiator. First irradiator under the program is to be installed at Massachusetts Insitute of Technology this spring (NU, March '61, 34) for experimentation on low-dose irradiation of clams and haddock; the Davis and Seattle irradiators are copies of the MIT facility. At Davis, emphasis will be on fruit; at Seattle, it will be on flounder and crab.

Meanwhile, AEC said it expected to submit to JCAE by Apr. 1 design studies being carried out by Brookhaven on transportable irradiators (radioisotope sources small enough to be moved by truck or rail flat-cars between geographical areas producing food of special interest for radiopasteurization). Brookhaven has also had under design a cesium-137 irradiator which might be located in Hawaii for low-dose work on produce.

Ohmart Reports Sharp Gain in Gage Sales

A maker of radionuclide gages for process control, Ohmart Corp., has reported whopping increases in both sales and earnings during 1960, reflecting a strong upsurge in industry interest in radiation gaging. Ohmart reported a 441% increase in earnings and an 82% increase in sales. The increases, a company official said, stemmed from purchases by the chemical industry, principally. "Ohmart supplies 22 of the 26 major chemical companies in the U. S., as well as many foreign concerns," Ohmart said. "As the chemical industry turns more and more to computer-controlled production, the need of Ohmart's beta and gamma flow-gages, with control-processing instrumentation, increases." Sales were $873,737 ($462,440 in '59), with earnings of $109,762 ($24,851 in '59).

Packard "Going Public" to Raise $1-million

After eleven years of private ownership, Packard Instrument Co. took the first step in February toward becoming a publicly-owned corporation. The firm filed with the Securities and Exchange Commission a proposal to sell 110,000 shares of common stock at $10/share—100,000 to the public, 10,000 to employees. President Lyle Packard, founder and sole owner, would hold 82% of the new stock, or about 505,000 shares. The firm's prospectus reported: 1. the net of $1-million to be raised in the offering would be used to repay bank loans, to intensify research-development, and possibly to fund a new building for consolidation of three separate operations: 2. Packard is considering construction of a plant in Europe; and 3. the firm's sales were $2.9-million in 1960—75% of this liquid-scintillation counters.

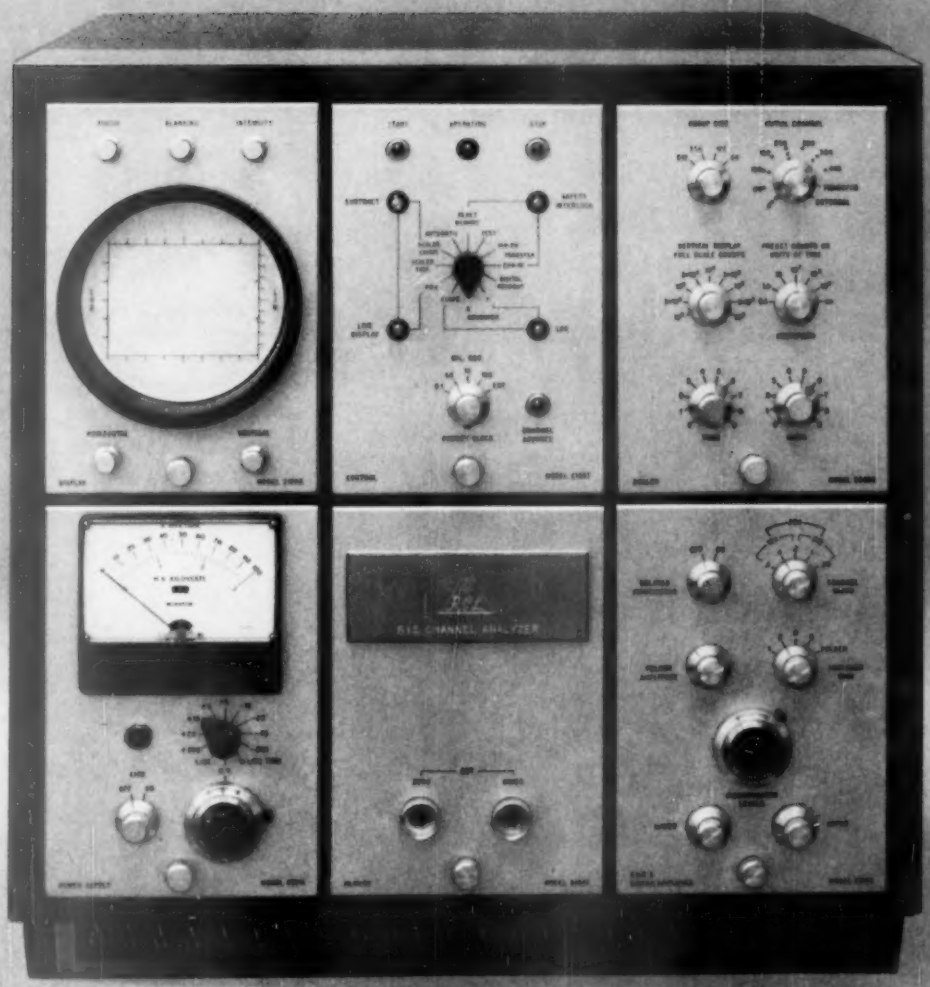
Army to Break Ground May 16 on New Food Center

Groundbreaking for this country's largest research center for radiation-preservation of food—under the Army Quartermaster Corps' military food program—has been scheduled for May 16 at Natick, Mass. Location of the center was shifted from Stockton, Calif., to Natick last year after a review of the Stockton plan. Natick will include a 24-Mev, 18-kw linear accelerator, a one-million-curie cobalt-60 irradiator, and associated facilities. Associated Nucleonics is architect-engineer for Natick, under the project management of Capt. Vincent Smith of AEC's New York Operations Office. Construction schedule calls for completion by the fall of 1962.

NENC Pulls Out of Nuclear Industries Group

New England Nuclear Corp. said last month it had decided to pull out of the Nuclear Industries "family" (NU, March '61, 29) and will have its sales force.

THE NEW SOLUTION
FOR YOUR PULSE HEIGHT ANALYSIS
AND COUNTING PROBLEMS



512 Channel Pulse Height Transistor Analyzer and Scaler*

Memory capacity—1,000,000 counts per channel in coded decimal . . . Switch selected log or linear display . . . Linear amplifier . . . Live display during accumulation . . . Channel subgrouping in multiples of 64 . . . Super-stable ± H. V. power supply—300 to 3000 V. at 5 ma . . . Preset live time—0.1 milliseconds to 99,000 seconds in 700 steps . . . Preset Time Scaler Mode for decay studies

*Also available with 256 Channel Memory Module

ALL THESE SPECIAL FEATURES ARE AVAILABLE AT NO EXTRA COST WITH STANDARD RCL MODELS 20618 (512) AND 20617 (256).

for additional information write:

RADIATION COUNTER LABORATORIES, INC.
5121 WEST GROVE • SKOKIE, ILLINOIS, U.S.A. • YORKTOWN 6-8700

NEW FROM NUCLEAR-CHICAGO

THE LOGIC SERIES OF INTEGRATED COUNTING SYSTEMS

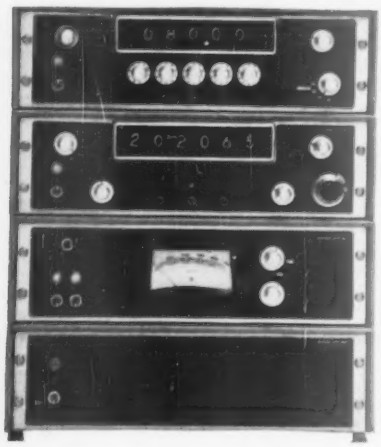
THE SECOND GENERATION OF NUCLEAR INSTRUMENTS

Functions of geiger counting, integral proportional counting, integral scintillation counting.

Modules, from top:
Model 8600 Timer
Model 8250 Scaler
Model 8200 High Voltage Supply
Model 8905 Cooling Base

Add-on Modules (not shown)
Model 8400 Digital Recorder
Model 8350 Linear Ratemeter
Model 8360 Logarithmic Ratemeter
Models 8410-11 Graphic Recorder

LOGIC 801

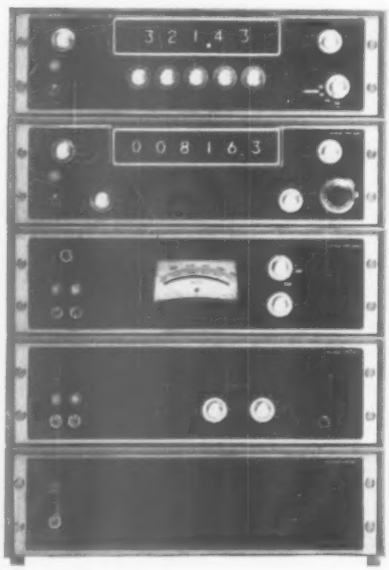


Functions of proportional counting, scintillation counting, geiger counting.

Modules, from top:
Model 8600 Timer
Model 8250 Scaler
Model 8200 High Voltage Supply
Model 8150 Linear Amplifier
Model 8905 Cooling Base

Add-on Modules (not shown)
Model 8400 Digital Recorder
Model 8350 Linear Ratemeter
Model 8360 Logarithmic Ratemeter
Models 8410-11 Graphic Recorder

LOGIC 802

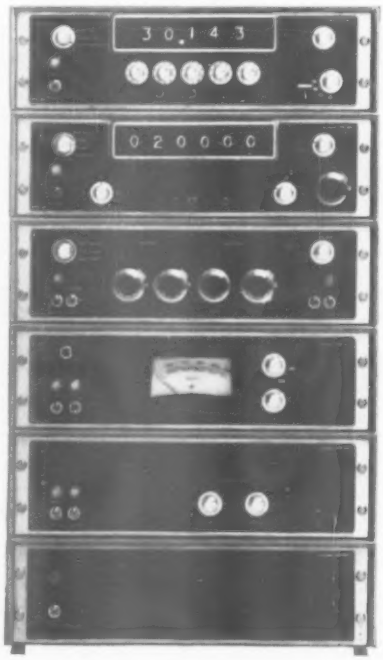


Functions of dual-channel window spectrometry, proportional and scintillation counting, geiger counting.

Modules, from top:
Model 8600 Timer
Model 8250 Scaler
Model 8300 Analyzer
Model 8200 High Voltage Supply
Model 8150 Linear Amplifier
Model 8905 Cooling Base

Add-on Modules (not shown)
Model 8400 Digital Recorder
Model 8350 Linear Ratemeter
Model 8360 Logarithmic Ratemeter
Models 8410-11 Graphic Recorder

LOGIC 803



Functions of dual-channel,
digital recording spectrometry,
100-channel step readout,
differential proportional
and scintillation counting,
geiger counting,
and programming versatility.

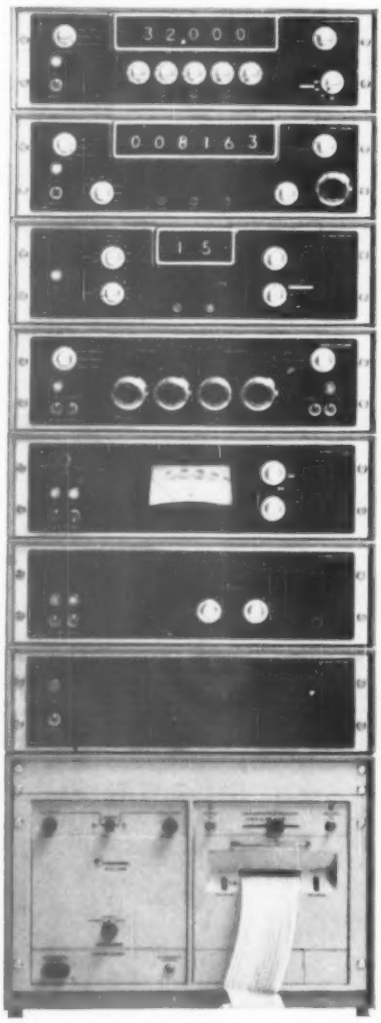
Modules, from top:

Model 8600 Timer
Model 8250 Scaler
Model 8551 Stepping Programmer
Model 8300 Analyzer
Model 8200 High Voltage Supply
Model 8150 Linear Amplifier
Model 8905 Cooling Base
Model 8400 Digital Recorder

Add-on Modules (not shown)

Model 8350 Linear Ratemeter
Model 8360 Logarithmic Ratemeter
Models 8410-11 Graphic Recorder

LOGIC 804



In 1946, coinciding with the first commercial shipment of reactor-produced radioactivity, Nuclear-Chicago delivered its first nuclear instruments.

The intervening years have seen many advances in the theory, design and manufacture of nuclear instrumentation. Many of these advanced instruments have been produced by Nuclear-Chicago—more perhaps than any other company in the field.

Three years ago Nuclear-Chicago undertook an appraisal of nuclear instrumentation needs and instrument availability. A decision was made to design a completely new family of instrument modules which, when linked together, would function as integrated counting systems achieving a new standard of reliability and performance.

Nuclear-Chicago's engineering staff approached the problem with no design or production obligations to past practice. They had the singular advantage of a second look—enriched by the perspective of fifteen years of experience.

Now, Nuclear-Chicago introduces the result—the Logic Series of Integrated Counting Systems—the second generation of nuclear instruments.

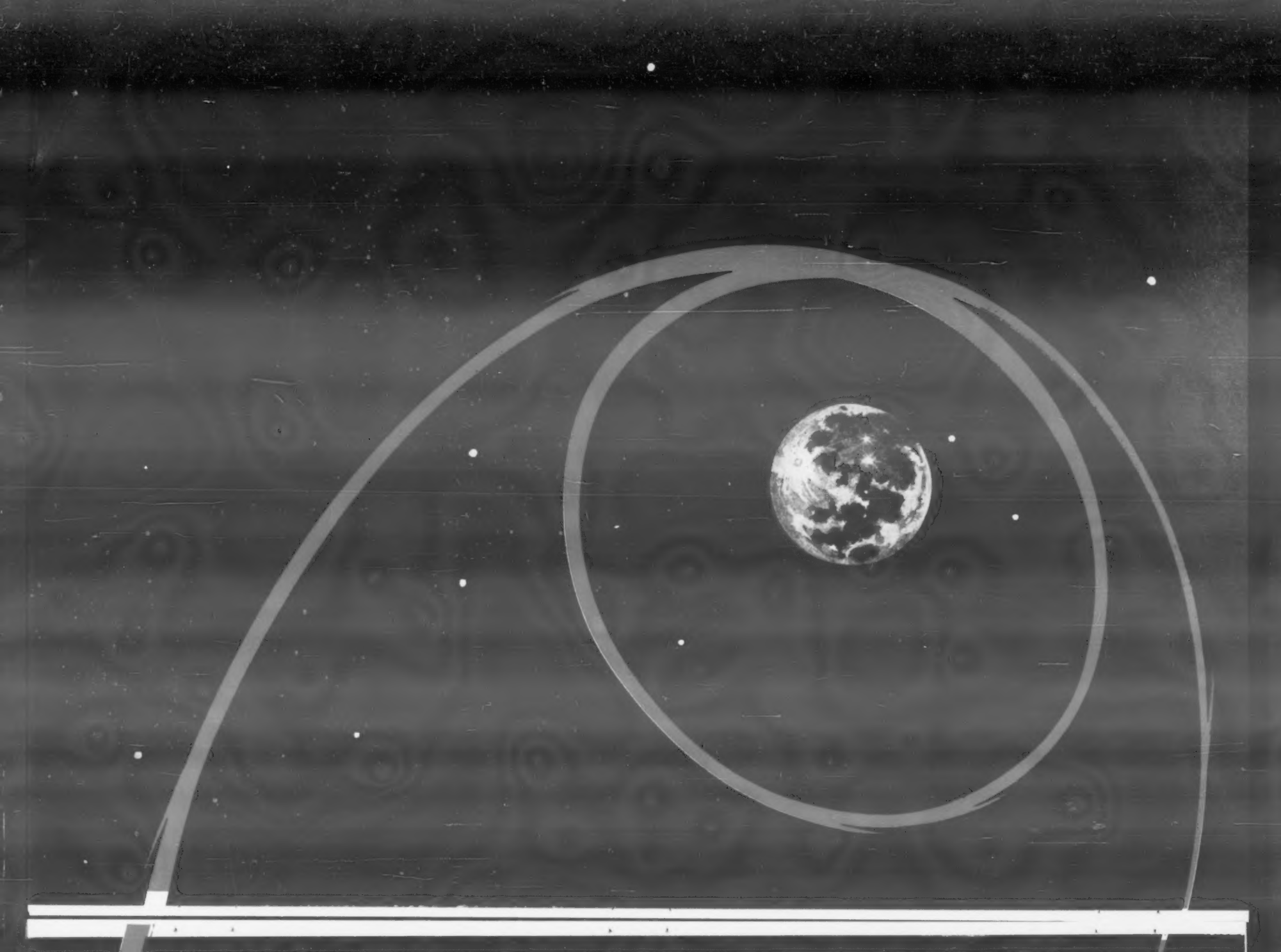
In design and manufacture the Logic Series represents the finest nuclear measuring instruments available. All components are conservatively rated to insure highest continuing performance. Each instrument is guaranteed, without reservation, to perform comfortably within its exacting specifications.

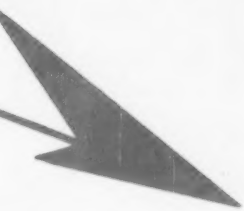
So high, in fact, is the reliability of the Logic Series that the one-year warranty originally established by Nuclear-Chicago has been extended to two years for these systems.

The functions of the various basic systems in the Logic Series are listed to the left above their respective illustrations. For technical specifications of these systems, derivative systems, or of their individual components, please write to Nuclear-Chicago.

nuclear-chicago
CORPORATION

345 EAST HOWARD AVENUE DES PLAINES, ILLINOIS





NATIONAL
TRADE-MARK

GRAPHITE...

Today's "Hottest" Material for Tomorrow's Airborne Reactors!

NUCLEAR POWER . . . for boosters . . . for energy . . . for space vehicles to carry man deep into the cosmos and back to earth . . . !

This is the next giant step of the Atomic Age . . . an age born at Stagg Field eighteen years ago in an atomic pile of super high-purity graphite principally furnished by National Carbon Company.

In nuclear reactors fission energy generates fantastic temperatures . . . heat that must be controlled and contained. This is a job best done by *graphite,* since no other material has so many useful nuclear properties.

Graphite is literally *created by heat* . . . by baking carbon at temperatures above 5,000° Fahrenheit. Graphite has remarkable resistance to thermal shock . . . becomes *stronger* as temperature rises . . . maintains dimensional stability under the toughest operating conditions.

This amazing material is an excellent neutron moderator and reflector . . . easily meeting high temperature requirements. It serves as a matrix for dispersion of fuel particles . . . as a structural element. It machines easily to close tolerances. In addition, graphite is used in rocket nozzle inserts and nose cones.

Today, National Carbon Company offers optimum capabilities for customized graphite . . . *plus* research, development, and manufacturing experience embracing every phase of *nuclear* graphite and its potential for propulsion.

Graphite could be the answer to more than one of your requirements. Why not write for full information on versatile, durable "National" graphite?

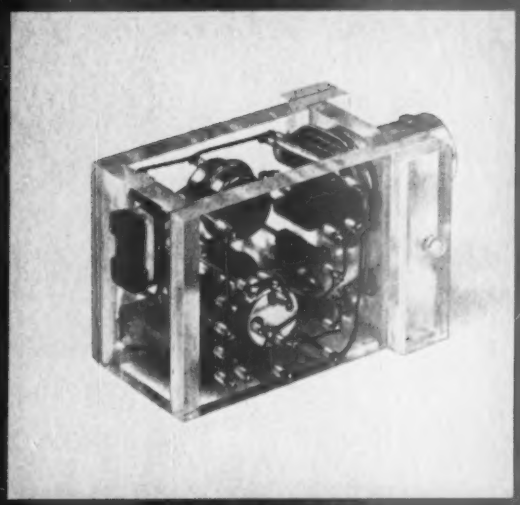
"National" and "Union Carbide" are registered trade-marks for products of

NATIONAL CARBON COMPANY

UNION CARBIDE

Division of Union Carbide Corporation • 270 Park Avenue, New York 17, N. Y.

Radiation Handler—Mobot® Mark II



Detector—Preamplifier

Opportunities in basic research or development engineering in our expanding

nuclear electronics laboratory

programs: Operating in a radiation environment is a many faceted problem that offers challenge and growth to many kinds of engineers and scientists in our Nuclear Electronics Laboratory. They are contributing to such projects as: simulating radiation environment to study the radiation resistance of electronic components and systems; the design of LINACS, producing either electron beams, gamma rays or neutron pulses, uniquely adapted to current needs in radiation research, effects testing, medical therapy, sterilization, industrial processing and radiography; radiation detection and measurement with such devices as the Hughes charged particle detector; and mobile remote handling equipment, such as the MOBOT®.

facilities: The laboratory's research and test facilities include a 1 Mev beam generator, an underground LINAC installation and a 500-curie cobalt radiator. An improved 10 Mev LINAC is being constructed. The unexcelled facilities of the Hughes Aircraft Company, which include 5 million square feet of research development and manufacturing area, support the technical competence of a staff which is a demonstrated leader in electronic system and component development.

openings: **Physicists, Electronic Engineers and Mechanical Engineers to participate in the development of High Power Particle Acceleration, Solid State Radiation Detectors and associated data processing equipment or mobile remote handling systems.**

If you are a graduate electronic engineer, physicist, mechanical engineer or metallurgist and have experience which is applicable to the above programs, please airmail your resume to:

Mr. Robert A. Martin, Supervisor, Scientific Employment, Hughes Aerospace Engineering Division, 11940 W. Jefferson Blvd., Culver City 22, California.

WE PROMISE YOU A REPLY WITHIN ONE WEEK

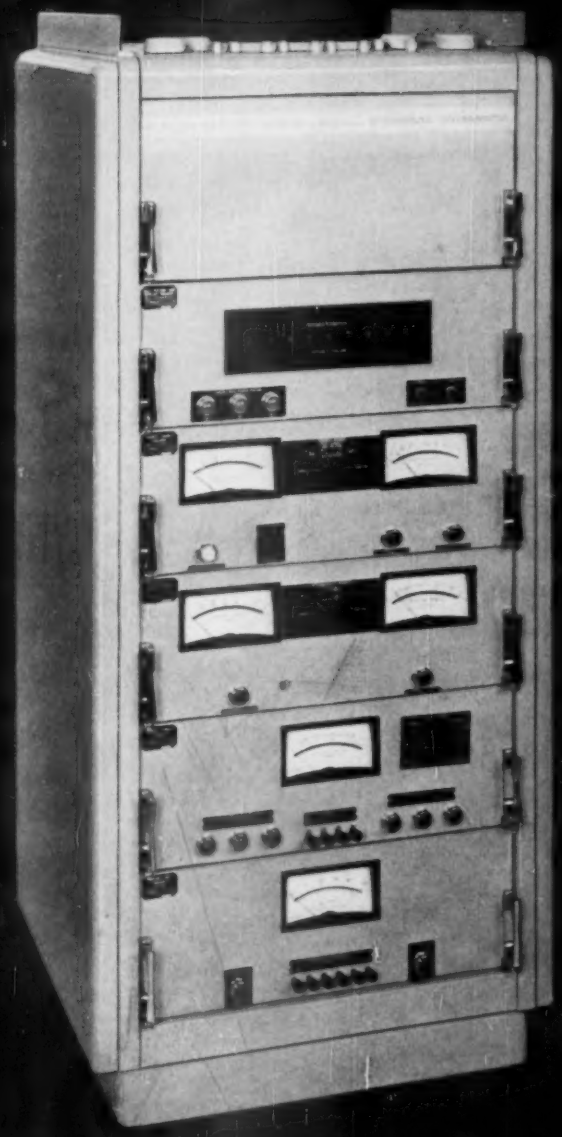
Creating a new world with Electronics

HUGHES

HUGHES AIRCRAFT COMPANY

AEROSPACE ENGINEERING DIVISION

A Step Ahead of the State of the Art in Reactor Controls



World's most efficient juice squeezer

Here's an important advance towards making atomic power competitive in cost with conventionally produced power.

These completely solid-state, modularized control systems, by General Dynamics/Electronics, help squeeze out many hours more of electrical power per month from nuclear reactors.

Here's why. Up to now, the lack of reliability in control systems has resulted in a costly amount of down time for the system itself . . . and for the reactor. This new equipment slashes that down time with a new plateau of fail-safe operation, achieved through 100% use of transistors and key-point use of solid-state relays.

Additional hours of power are gained through the inherent ability of these systems to speed service procedures. While attending to their main functions—monitoring and controlling power level, rate of change of power level, pressure, temperature and coolant flow—General Dynamics/Electronics control systems check themselves continuously. Should the suspicion of a malfunction occur . . . scram rods drop and the address of the faulty part is flashed on the annunciator. The operator can pull the offending module and plug in a replacement in minutes—compared to the hours previously needed to get back into service.

If you're concerned with nuclear power—marine, portable, research or commercial—write for the illuminating facts.

Engineers and scientists interested in challenging opportunities are invited to send résumés to Manager, Engineering Employment.

GENERAL DYNAMICS | ELECTRONICS
MILITARY PRODUCTS DIVISION ROCHESTER 3, N.Y.

GENERAL DYNAMICS | ELECTRONICS IS A DIVISION OF GENERAL·DYNAMICS CORPORATION

WANTED IN FLORIDA

YOUR COMPANY TO JOIN WITH US IN PINELLAS COUNTY

Here's one of the few areas in America where it is possible to attract personnel in every category without difficulty.

Why? — No executive or employee need be more than 15 minutes away from home and garden, from fresh and salt water, fishing, bathing, boating, water skiing . . . no more than 15 minutes away from schools, churches, shopping centers, recreational and social activities.

All this, plus a favorable business climate . . . and SUN-sational living all year, in this enchanting land of flora and fauna.

Executive decisions, after extensive site location surveys in many areas of the nation, have resulted in major companies locating here. Their managements will gladly give you the result of their findings.

NOTE: Persons seeking positions please write Florida State Employment Service, 1004 First Avenue North, St. Petersburg.

For complete information communicate in confidence with:

GREATER ST. PETERSBURG - CLEARWATER INDUSTRY COUNCIL
GREATER ST. PETERSBURG CHAMBER OF COMMERCE
Jack Bryan, Industrial Director / Department N, St. Petersburg, Florida

Clearwater
Dunedin
Gulfport
Indian Rocks
Largo
Madeira Beach
Oldsmar
Pass-a-Grille Beach
Pinellas Park
Safety Harbor
St. Petersburg
St. Petersburg Beach
Tarpon Springs

From headquarters
for radiation shielding materials:

FEDERATED LEAD PRODUCTS

Federated has fabricated Asarco Lead into shielding devices in numerous designs and widely varying weights. **Interlocking Bricks***, for example, have a unique design to provide a full inch of shield for every inch of lead supplied. Other Federated perfected products include lead sheet and plate for permanent installations, available in different thicknesses, lengths, widths; numerous stock sizes of isotope containers; storage, disposal and shipping containers in weights up to 25 tons; lead shot to fill hollow receptacles; lead wool for cold caulking; and special castings to order of elbows, bushings, piping and other components. Write or call for Bulletin No. 193, "Lead For Radiation Shielding." Federated Metals Division, American Smelting and Refining Company, 120 Broadway, New York 5, REctor 2-9500, or call your nearest Federated sales office.

*Patent Pending

ASARCO
AMERICAN SMELTING AND REFINING COMPANY

FEDERATED METALS DIVISION

Where to call for information:

ALTON, ILLINOIS
Alton: Howard 5-2511
St. Louis: Jackson 4-4040

BALTIMORE, MARYLAND
Orleans 5-2400

BIRMINGHAM, ALA.
Fairfax 2-1802

BOSTON 16, MASS.
Liberty 2-0797

CHICAGO, ILL. (WHITING)
Chicago: Essex 5-5000
Whiting: Whiting 826

CINCINNATI, OHIO
Cherry 1-1678

CLEVELAND, OHIO
Prospect 1-2175

DALLAS, TEXAS
Adams 5-5034

DETROIT 2, MICHIGAN
Trinity 1-5040

EL PASO, TEXAS
(Asarco Mercantile Co.)
3-1852

HOUSTON 29, TEXAS
Orchard 4-7611

LOS ANGELES 23, CALIF.
Angelus 8-4291

MILWAUKEE 10, WIS.
Hilltop 5-7430

MINNEAPOLIS, MINN.
Tuxedo 1-4109

NEWARK, NEW JERSEY
Newark: Mitchell 3-0500
New York: Digby 4-9460

PHILADELPHIA 3, PENNA
Locust 7-5129

PITTSBURGH 24, PENNA.
Museum 2-2410

PORTLAND 9, OREGON
Capitol 7-1404

ROCHESTER 4, NEW YORK
Locust 5250

ST. LOUIS, MISSOURI
Jackson 4-4040

SALT LAKE CITY 1, UTAH
Empire 4-3601

SAN FRANCISCO 24, CALIF.
Atwater 2-3340

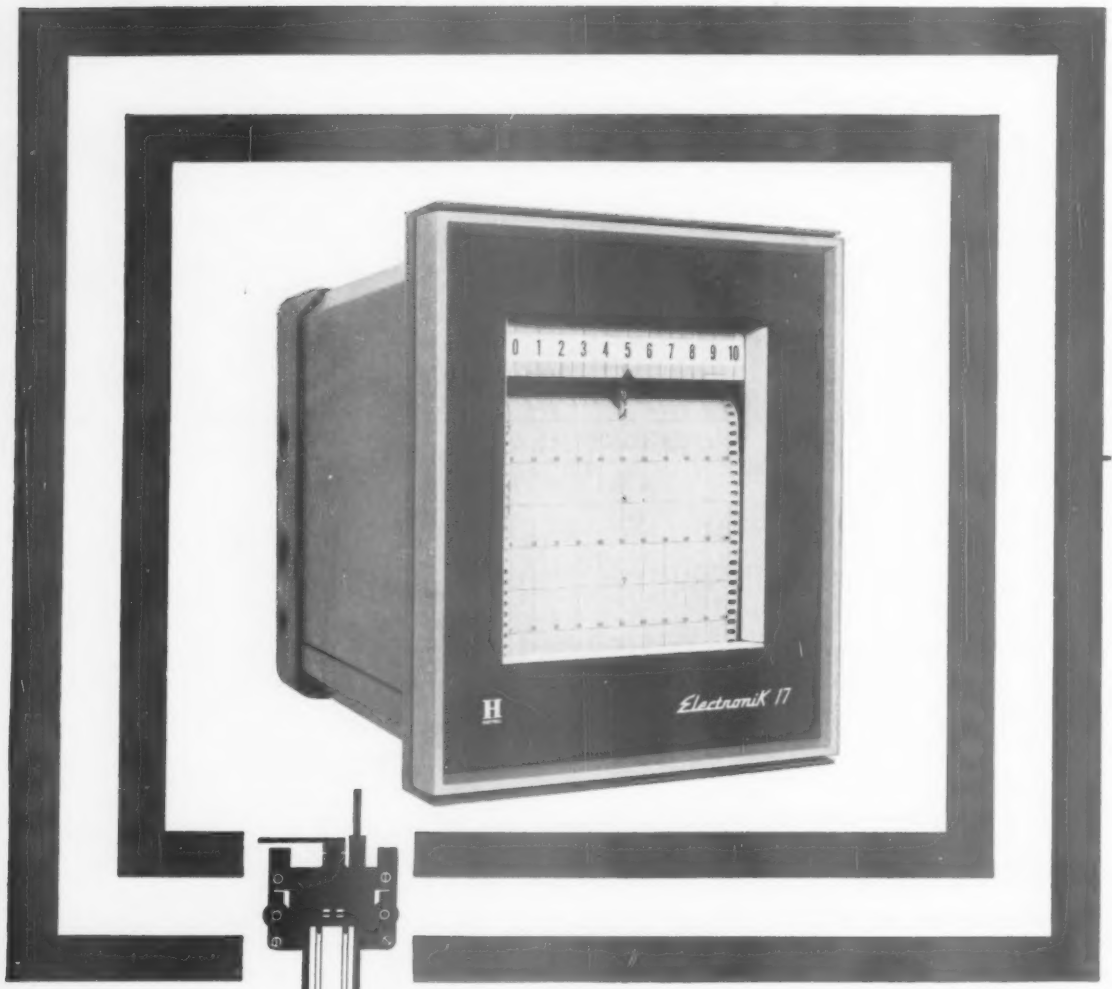
SEATTLE 4, WASHINGTON
Main 3-7160

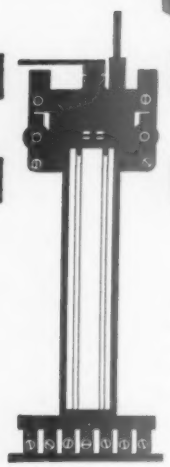
WHITING, IND. (CHICAGO)
Whiting: Whiting 826
Chicago: Essex 5-5000

IN CANADA: Federated Metals Canada, Ltd.
Toronto, Ont., 1110 Birchmount Rd., Scarborough, Phone: Plymouth 73246

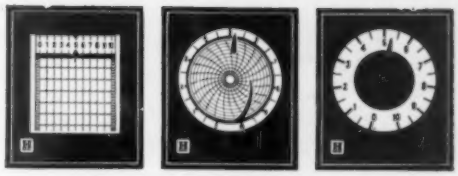
Montreal, P.Q., 1400 Norman St., Lachine, Phone: Melrose 7-3591

the advanced, all-new ElectroniK 17





NO SLIDEWIRE, NO SLIDEWIRE PROBLEMS. The unique STRANDUCER rebalancing element replaces the conventional slidewire. It works on the strain gage principle and consists of four looped wire strands which form the resistance legs of a Wheatstone bridge. Both STRANDUCER and pen carriages are linked to the potentiometer balancing motor. A change in electrical input causes the balancing motor to change the tension—and electrical resistance—of the STRANDUCER, to reposition the instrument pen or pointer. The STRANDUCER is unaffected by corrosive atmospheres and has no contactors. It has unusually long life and infinite resolution and is unaffected when the instrument operates in ambient temperatures up to 130° F.



will save you more time, trouble, dollars, and maintenance than any other potentiometer on the market today!

- New *STRANDUCER** replaces slidewire
- New control system with plug-in units
- New modular construction
- New economy

. . . and other pace-setting features

ElectroniK 17 potentiometers are completely new Honeywell recording and control instruments, compact enough to fit standard 19-inch relay racks. They perform reliably, have ±0.25% calibrated accuracy and incorporate new design advances which make them the easiest of all potentiometers to operate, convert, and maintain.

You can get *ElectroniK 17* instruments as strip or circular chart recorders or circular scale indicators. You can get electric contact control with up to 8 contacts. Control units are of plug-in type.

With *ElectroniK 17* potentiometers, you not only get uninterrupted performance, but also save money in initial cost, operating expense, and maintenance. You will find this new potentiometer far more economical to operate than any other available today.

For complete information on the *ElectroniK 17*, call your nearby Honeywell field engineer or write to MINNEAPOLIS-HONEYWELL, Wayne and Windrim Avenues, Philadelphia 44, Pa. — In Canada, write Honeywell Controls, Ltd., Toronto 17, Ontario.

Honeywell

First in Control

SINCE 1885

MODULAR CONSTRUCTION, PLUG-IN COMPONENTS

make ElectroniK 17 easiest of all potentiometers to operate, convert, maintain.

INTERCHANGEABLE DISPLAY MODULE. You can switch easily from strip to circular chart, to circular scale operation . . . reduce your spare parts inventory because you can stock a single spare module for several instruments.

FRONT ADJUSTMENTS. You adjust damping and gain from the front of the instrument, using only a screwdriver.

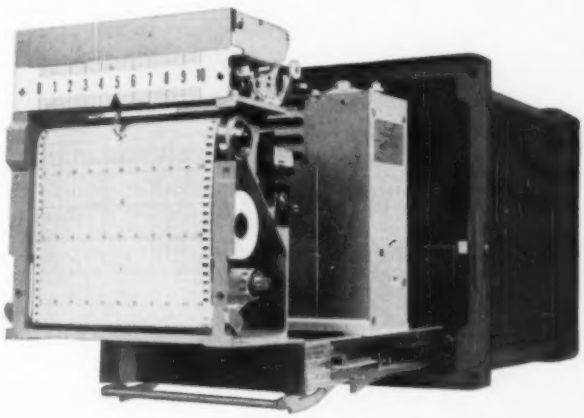
QUICK-CHANGE DRIVE GEARS. You can change chart speed to ½ or 2 times basic speed in a matter of seconds by replacing quick-change drive gears. Standard chart speeds: 1, 2, 6, 10, or 60 inches per hour.

EASY RANGE AND ACTUATION CHANGE. Simply change range card attached to actuation board. Universal reference junction compensator serves *all* types of thermocouples; you can quickly remove it to convert to some actuation other than thermocouple. Filter network rejects loop stray signals.

PULL-OUT CHASSIS AND EXTERNAL TERMINAL BOARD. You can pull out the chassis to the service position without tools and without interrupting the operation of the instrument, or completely remove it.

COMPACT EASILY-REMOVED TRANSISTOR AMPLIFIER. With only a screwdriver you can remove the amplifier for servicing.

NO STANDARDIZATION. Zener diode constant current unit does away with need for battery and standardizing mechanisms.



*Trademark—Minneapolis-Honeywell Reg. Co.

HONEYWELL INTERNATIONAL Sales and Service offices in all principal cities of the world. Manufacturing in United States, United Kingdom, Canada, Netherlands, Germany, France, Japan.

ANOTHER ULTRASONIC FIRST...
THICKNESS GAGING WITHOUT CONTACT

Tube scanner for VIDIGAGE® thickness gaging without contact.

Thickness gaging by means of the ultrasonic resonance technique can now be accomplished by immersion without contact. This is extremely advantageous because:

- it eliminates transducer wear
- maintains uniform coupling of energy between transducer and work surface (this in turn makes the test more reliable!)
- avoids possible damage to work surface caused by transducer contact
- substantially increases inspection speeds

When the water column is of sufficient length the VIDIGAGE® does not respond to the water resonances. As a result the resonance thickness of the work piece can be detected by itself on the VIDIGAGE screen.

In order to take full advantage of this immersion system, the VIDIGAGE had to be modified. The modified VIDIGAGE then surpassed all expectations, especially in the gaging of small diameter, high accuracy tubing.

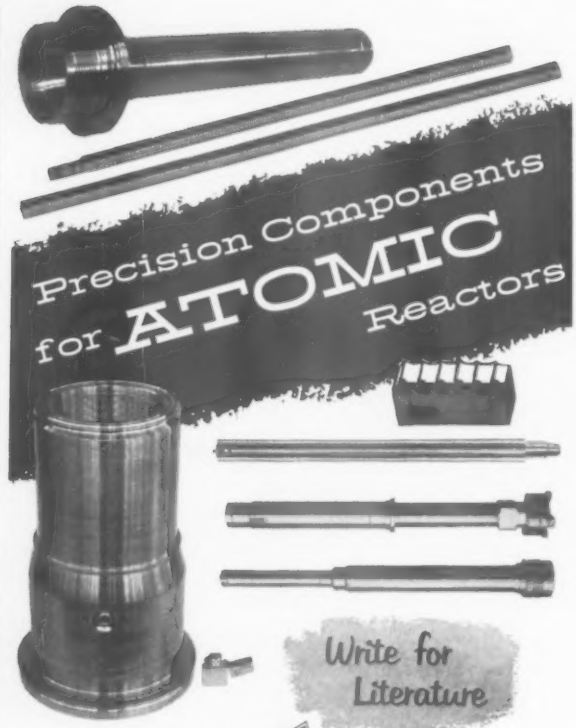
This development is another in the long line of BRANSON engineering break-throughs, which enables industry to solve its problems by means of ultrasonic testing. The next time you have a testing problem call BRANSON and see how fast BRANSON will find the best solution in the shortest possible time.

SINCE 1946 — THE RESPECTED NAME IN ULTRASONICS

BRANSON INSTRUMENTS, INC.

Ultrasonic Test Division

14 Brown House Road, Stamford, Conn.



JERPBAK BAYLESS

34150 Solon Rd.
Cleveland 39, Ohio

THERMOCOUPLES
THAT WILL WITHSTAND 3000°F AND UP TO 50,000 PSI

LONG LIFE

Sheath Diameters, .04 to .32
Thermocouple Lengths to 100 ft.

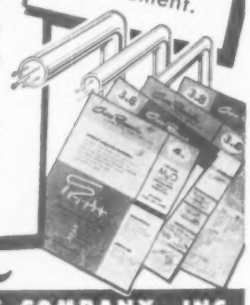
Complete Thermocouples made to every requirement.

NEW, SIMPLE CONSTRUCTION

A metallic sheath compressed over ceramic insulated wire. Sheath can be bent and weldments can be performed without loss of insulation.

Write for new Bulletins ▶ 3.8A for complete thermocouples. 4 for AEROPAK Ceramic insulated wire.

See V.S.M.F. Reel F



Aero Research INSTRUMENT COMPANY, INC.

Dept. N, 315 NORTH ABERDEEN ST. • CHICAGO 7, ILL.

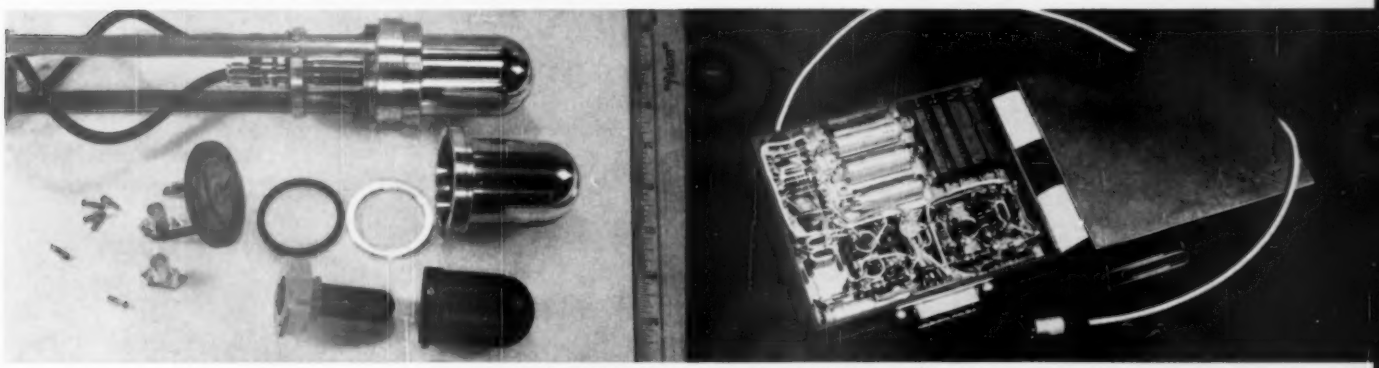
Sales Representatives throughout the United States and Canada

CONVAIR'S NUCLEAR EXPERIENCE IN DEPTH...

proven capability for
Space Instrumentation and Shielding

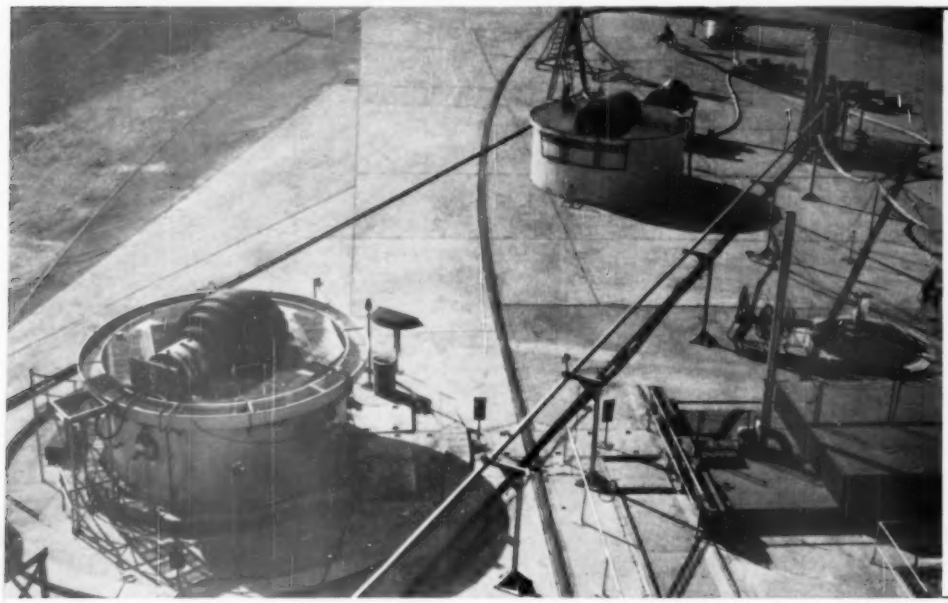
Convair, with nuclear know-how resulting from more than a decade of experience on vital projects, offers the nuclear industry *proven* capability in a wide range of atomic specialties. These include:

PRECISION SPACE INSTRUMENTATION Convair-Fort Worth is supplying the radiation detection instruments for the ARPA Environmental Test Satellite. This program will assure the success of a reliable Advent system. The scope of Convair's proven capability also includes the building of nuclear instruments to operate in adverse environments required for Aircraft Nuclear Propulsion applications. Other precision nuclear instruments which may satisfy your special requirements have been developed by Convair.

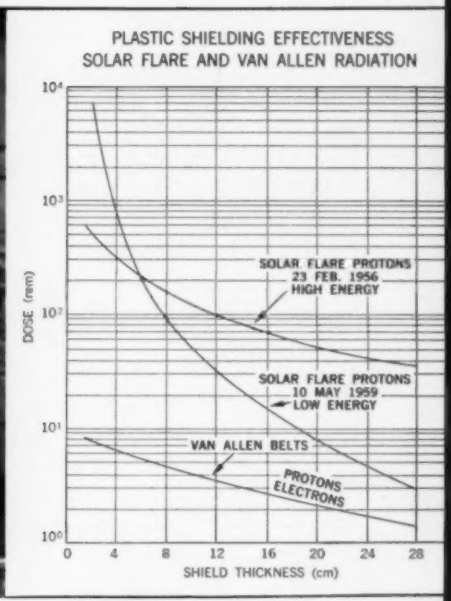


Convair-developed instruments for the ARENTS Satellite.

MAXIMUM PROTECTION SHIELDING As a prime contractor to the Air Force in the ANP program, Convair has gained extensive experience and abilities in the solution of shielding problems where maximum protection for minimum weight, bulk and cost are major factors. This proven capability has been extended to encompass study contracts with NASA. It is supported by strong analytical and theoretical capability, by facilities for the experimental evaluation of shield designs, and full mockup and production facilities.



Installation for a shield shaping experiment performed as a part of the development of optimum shields for the Air Force ANP program. The 3 MW ASTR reactor is shown in left foreground.

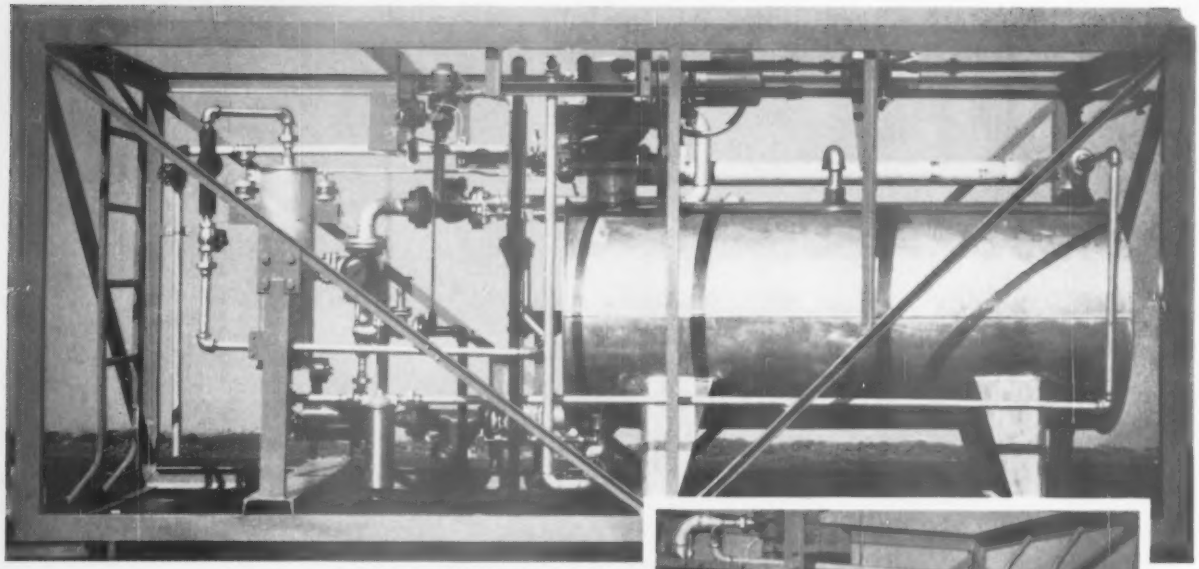


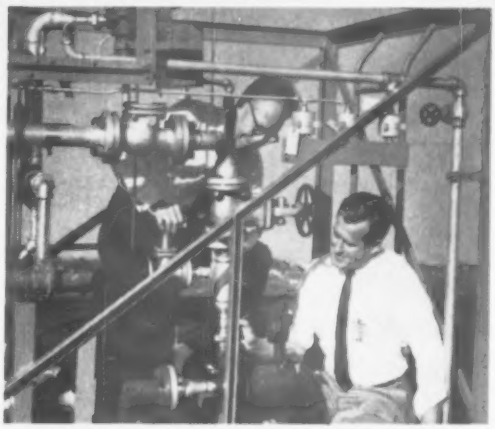
This graph illustrates thickness of plastic shield vs dose, for solar flares and the Van Allen belts — from the Convair study being performed on space shielding problems for NASA.

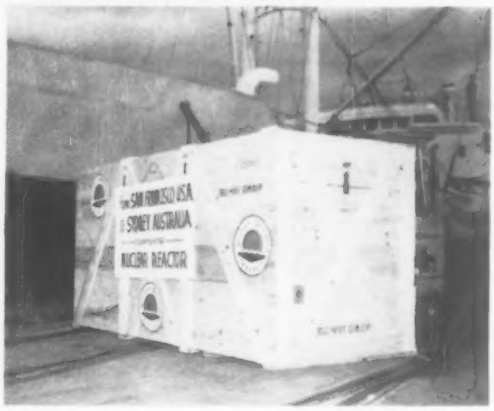
FOR DETAILED INFORMATION ON SPECIFIC INSTRUMENTS AND SPECIALIZED SHIELDING SOLUTIONS TO MEET *YOUR* NUCLEAR REQUIREMENTS, WRITE TO SPECIAL NUCLEAR PROJECTS, CONVAIR, P. O. BOX 748, FORT WORTH, TEXAS.

CONVAIR A DIVISION OF GENERAL DYNAMICS GD

SCIENTIFIC EXCELLENCE . . . WITH A SENSE OF MISSION







Process system for UTR-10 reactor after completion and testing. Lower right — pre-packaged system at dockside next to S.S. Sierra, which carried it to Australia for installation at Lucas Heights.

new ATL "pre-packaging" concept simplifies reactor installations

When it came time to install the process system on the Australian Atomic Energy Commission's new UTR-10 research reactor at Lucas Heights, New South Wales, the normal installation time was shrunk from weeks to a matter of hours. The secret was that 99% of the work had already been done — half a world away — at ATL's facilities in Mountain View, California.

Through its new pre-packaging technique, ATL was able to deliver a completely integrated process system to the customer. Upon arrival at the site, the 2500-pound unit was simply uncrated, lowered into place, and its pipes welded into the overall system. The customer received a fully tested, functioning system, saving significant amounts of time and labor, and avoiding the problems of on-site fabrication.

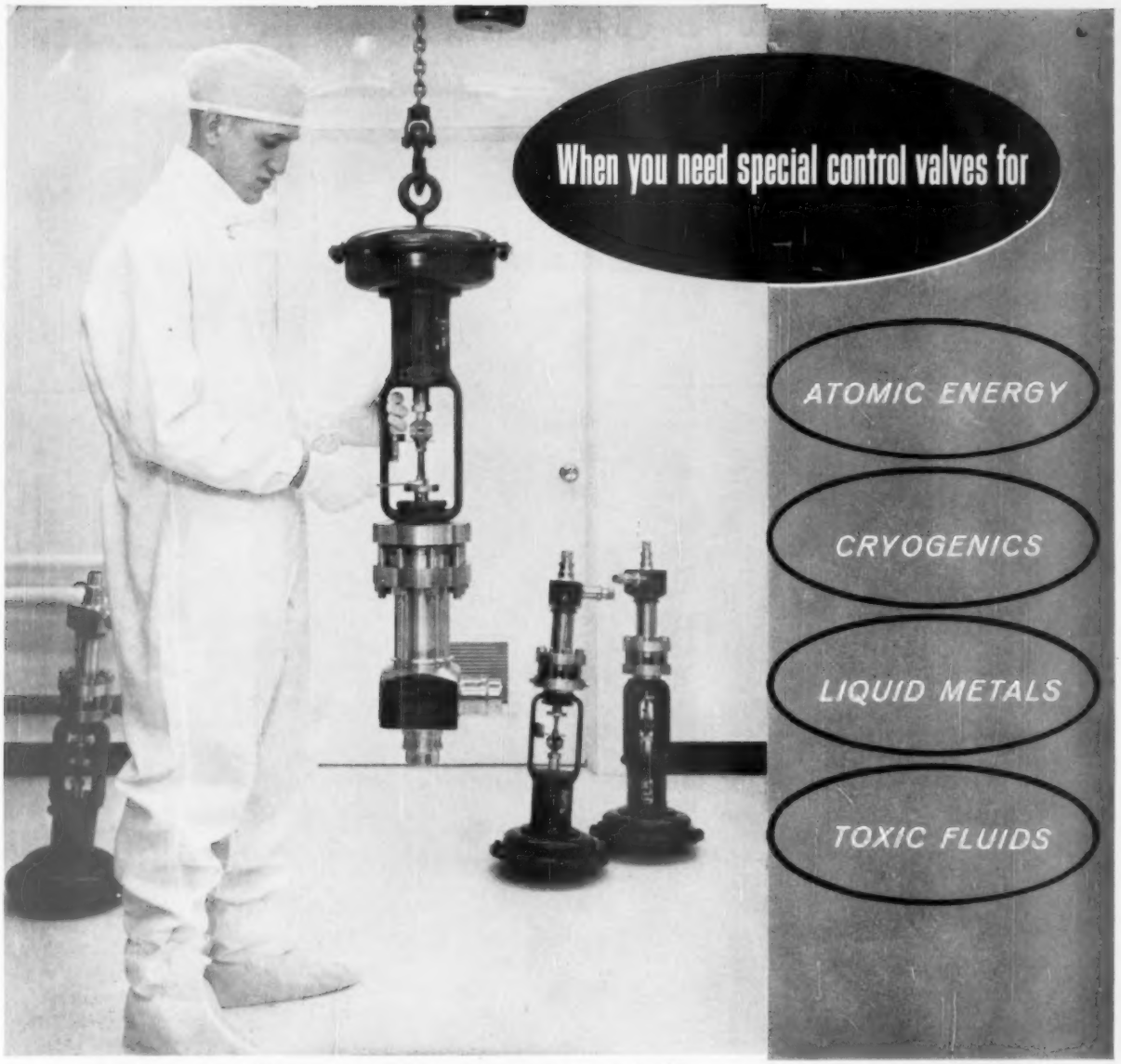
Australia's new research reactor is the fourth UTR-10 to go into operation outside the United States. Its performance, like its packaging, can be expected to enhance ATL's reputation for leadership in advanced nuclear technology.

ADVANCED *Technology* LABORATORIES

A DIVISION OF AMERICAN-Standard

369 WHISMAN ROAD • MOUNTAIN VIEW, CALIFORNIA

American Standard and Standard® are trademarks of American Radiator & Standard Sanitary Corporation



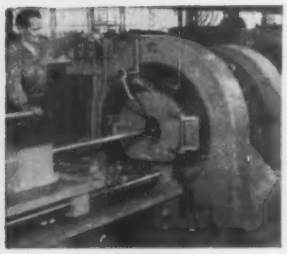
Fisher facilities and engineering skill are at your command

Typical of the special control valves assembled in the spotlessly clean Fisher white room is the Type SS-30, a high temperature angle body for controlling liquid metals at pressures up to 250 psi and temperatures of 1500° F. The SS-30 is also used in the atomic energy field and for control of toxic fluids in the chemical industry. Made of forged or bar stock material, the SS-30 has seal-welded joints, Stellite faced valve plug and seat, and bellows seal to prevent valve stem leakage. Stainless steel valve body is self-draining in both vertical and horizontal positions. SS-30 is tested by mass spectrometer when required to meet critical body and seat leakage rates.

Pressurized rooms, filtered air, pre-cleaned tools, and properly attired technicians will keep your equipment immaculate until capped and sealed for shipment. Fisher Governor Company, Marshalltown, Iowa. Plants in Woodstock, Ont., Rochester, England. Butterfly Valve Division: Continental Equipment Co., Coraopolis, Pa.

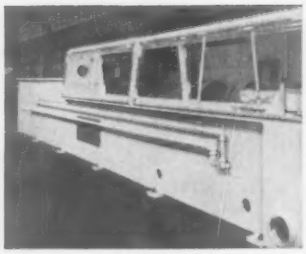
If it flows through pipe anywhere in the world ...chances are it's controlled by.....

FISHER® Governors SINCE 1880



SWAGING MACHINES

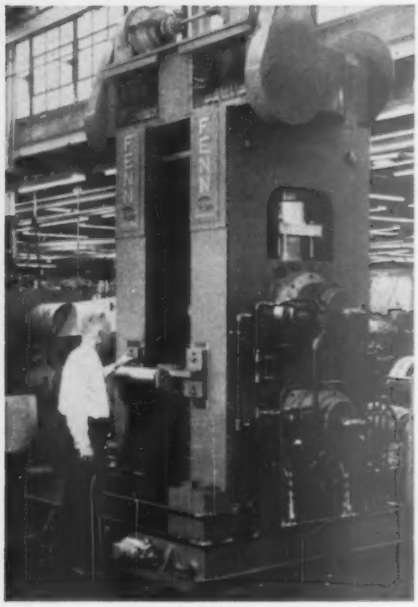
TURKS HEADS



DRAW BENCHES

WIRE AND TUBE MILLS

PRECISION • PERFORMANCE • DEPENDABILITY



ROLLING MILLS

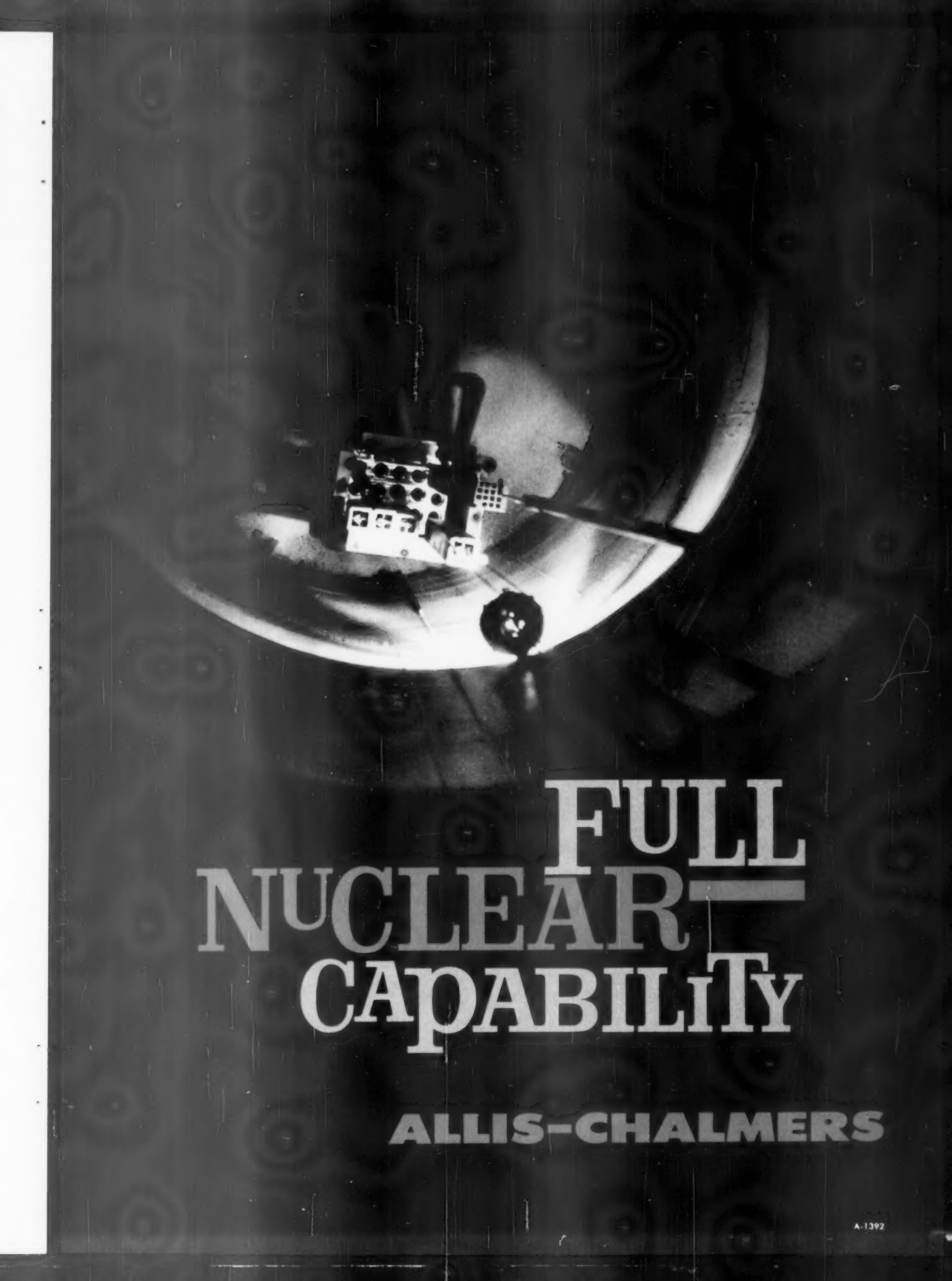
WIRE FLATTENING LINES

METAL FORMING MACHINES

that meet the challenges of the 60's

Within a relatively short span of years the name FENN has become well-known to users of metal forming equipment. In rolling mills . . . wire mills . . . in the nuclear industry . . . and wherever else ferrous or nonferrous metals are rolled, drawn, or formed to precision tolerances, Fenn machines are producing profits for their users. The extensive Fenn line is built on long experience in the manufacture of *precision* machinery and an equally long reputation for *performance* and *dependability*. Behind every Fenn machine is unexcelled engineering . . . from design to inplant checkout and continuing field service, plus an organization that strives to do every job better than the expected. Whatever your metal forming machinery requirements, you can depend upon your nearest Fenn representative for his experienced advice and practical help. Comprehensive literature will be promptly sent upon request. The Fenn Manufacturing Company, Fenn Road, Newington, Connecticut.

Designed and Built by FENN


FULL
NUCLEAR
CAPABILITY
ALLIS-CHALMERS
A-1392

Experienced in power, research and training reactors

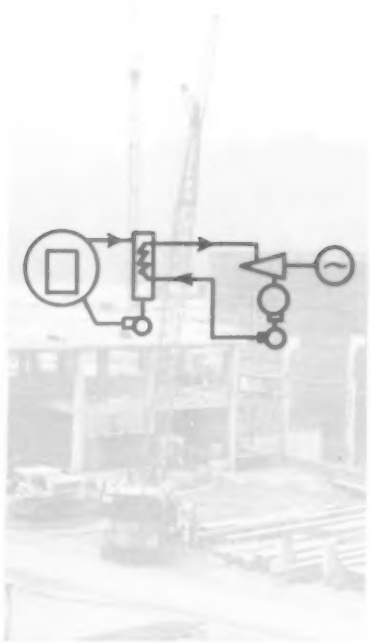
7

SEVEN FIRST HAND REPORTS

Full nuclear capability . . . in all phases of design, construction and operation. These are the goals which Allis-Chalmers set a short five years ago. Today they are accomplished facts.

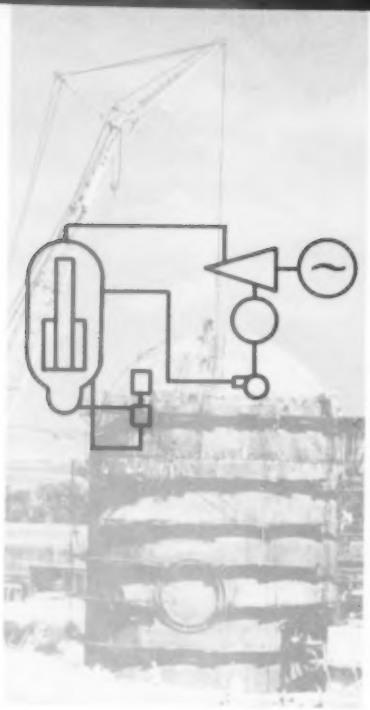
Only Allis-Chalmers has experience in both direct- and indirect-cycle boiling water reactors, fast breeder, gas-cooled, and pressurized-water reactors. A-C scientists and engineers believe that the knowledge and experience gained from these projects and others, such as the C-Stellarator project, will be an important contribution toward competitive nuclear power.

With nearly a century of experience in all areas of power production, it is only natural that A-C is a leader in the fast-paced fields of atomic energy. Whatever your plans in the field of atomic energy, you should investigate what Allis-Chalmers can do toward serving your needs. You may well be interested in receiving the new booklet "Atomic Energy at Allis-Chalmers." Write or wire for your free copy. Atomic Energy Division, **Allis-Chalmers,** Milwaukee 1, Wisconsin.

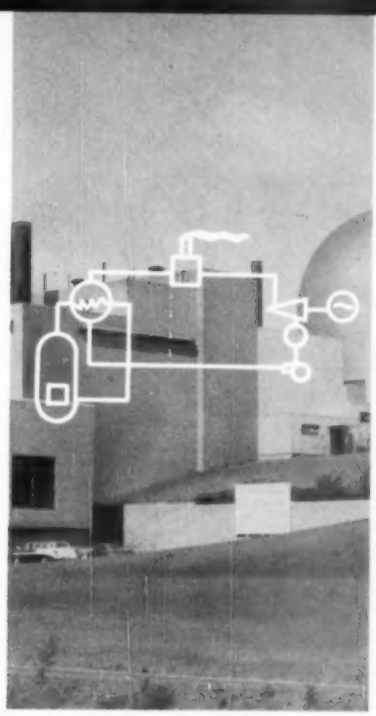


"GAS COOLED

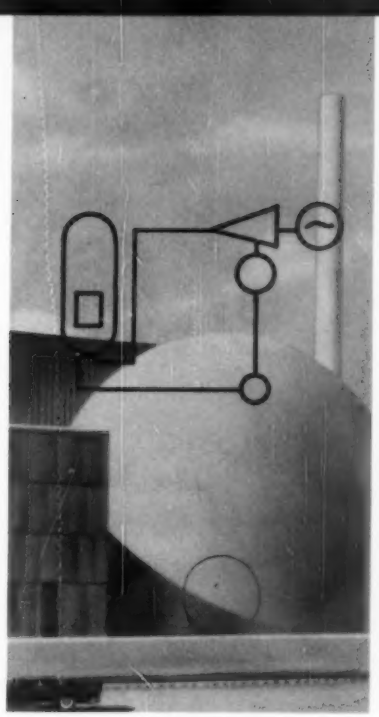
The first U. S. gas-cooled nuclear plant, this experimental reactor for Oak Ridge is rated at 85,000 kwt. We performed the conceptual and final design and detailed engineering on this helium-cooled, graphite-moderated reactor."



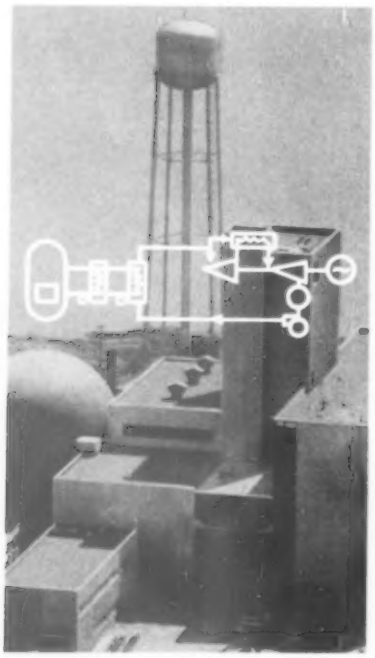
"BOILING WATER We have the responsibility for design, engineering, fabrication and construction of the Pathfinder Power Station. Of the direct-cycle type, this 66,000-kwe boiling water reactor is the first power reactor with integral nuclear superheat."



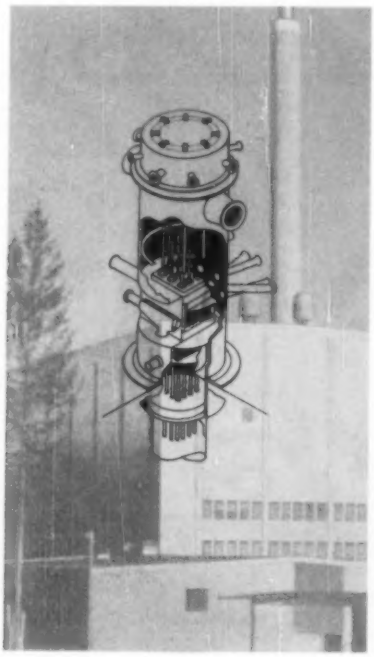
"BOILING WATER Allis-Chalmers is also experienced in indirect-cycle-type boiling water reactors. The A-C reactor for the Rural Cooperative Power Association of Elk River, Minn., is the first boiling water reactor in the AEC's second-round power demonstration. It is rated at 22,000 kwe."



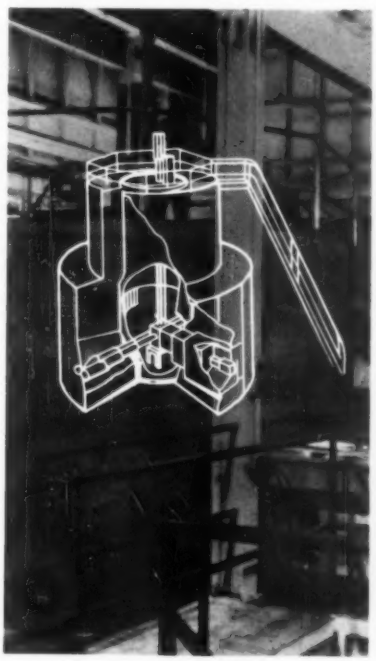
"PRESSURIZED WATER Resulting from an Atomic Energy Commission contract award, Allis-Chalmers has performed the nuclear design work on a 40,000-kwt pressurized-water reactor system for experimental low-temperature process heating applications."



"FAST BREEDER As a member of APDA and of PRDC, Allis-Chalmers has participated in the design of the 300,000-kwt Enrico Fermi reactor and is furnishing reactor and system components, including the turbine-generator."



"RESEARCH AND TEST In many countries throughout the world Allis-Chalmers research and test reactors are now in operation or under construction. These reactors range in size from 1,000 to 30,000 kw."



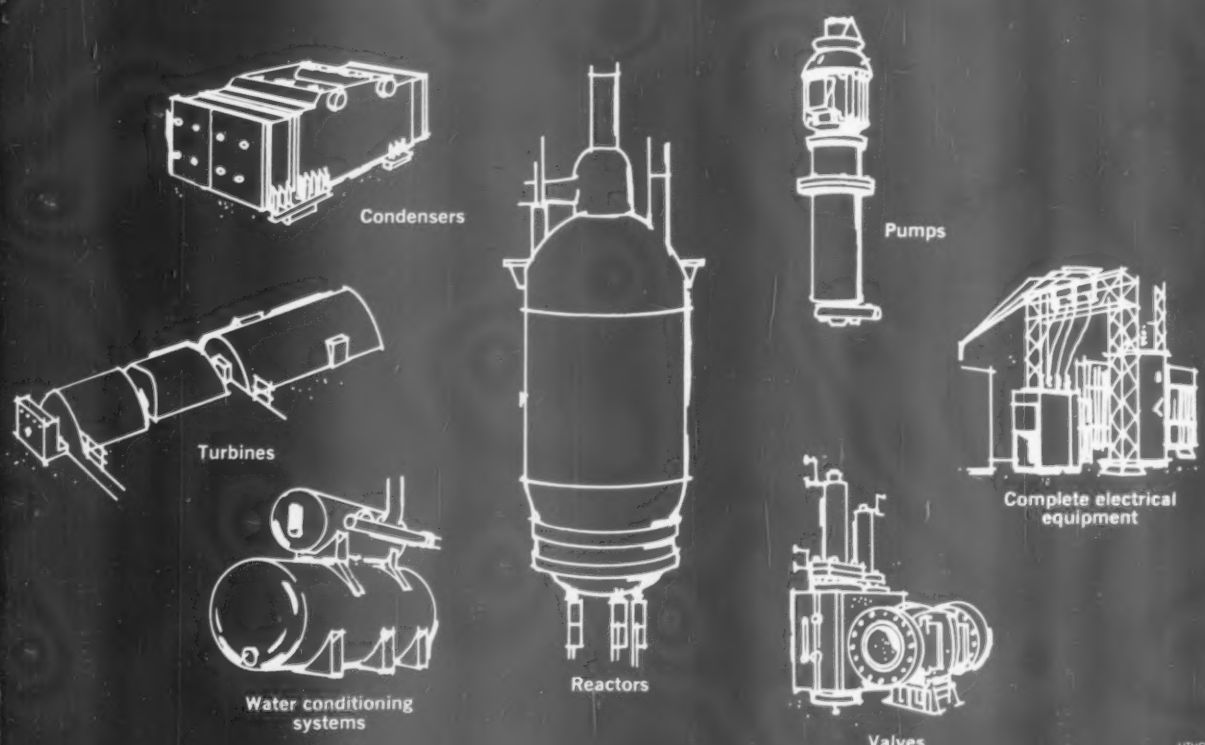
"TRAINING We offer a variety of training reactors with operating power levels from 1 kw to 1,000 kw. These reactors require neither a containment shell nor special utilities. They may be erected in ordinary buildings."

COMPLETE SYSTEMS RESPONSIBILITY

From the "talk-about-it" stages through to the start-up and operation of a complete nuclear facility, Allis-Chalmers provides a rare balance of technology, experience and component manufacture. Long a leader in the power generation field, Allis-Chalmers offers thorough knowledge and a wide range of products for any system: Turbines, condensers, pumps, valves, water conditioning systems, transformers, circuit breakers, switchgear, electrical control and regulating equipment... and also nuclear reactors of all types, plus special development projects into new methods of energy conversion, such as thermonuclear fusion, magnetohydrodynamics and the fuel cell.

PROFESSIONAL OPPORTUNITIES:
Would you like to work with Allis-Chalmers highly qualified atomic scientists and engineers? . . . *Write to* **Allis-Chalmers,** *Atomic Energy Division, Milwaukee 1, Wisconsin, for information on employment opportunities.*

A-C ALLIS-CHALMERS



LITHO IN USA D&J-6

Key to a New Technological Era:

Nuclear Energy in Space

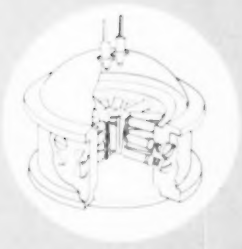
As the steam engine gave man mastery of the sea and the gasoline engine gave him mastery of the air, so nuclear power is destined to make possible man's conquest of space. Scientists and engineers, even as they now prepare for man's first timid ventures into space, are confident that we will shortly see the day when human explorers will literally leave their footprints on the moon and elsewhere in the solar system. That nuclear energy will play the key role in this ambitious undertaking is equally certain. Nuclear power for space missions will mean the difference between mere instrumented probes and practical manned spacecraft.

Space technology employed in terrestrial pursuits again will involve nuclear energy. The first nation to exploit the greater payload potential of nuclear propulsion systems may take a commanding lead in the arms race of tomorrow in which the means both of attack and defense will be concentrated in super-satellites orbiting the globe. On the other hand, in the cause of international peace, three well-placed communication satellites powered by SNAP-8 reactors could beam ten television channels simultaneously to all points on the face of the earth.

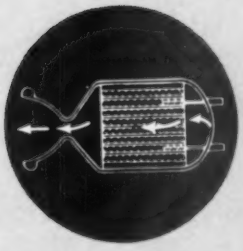
In the first section (p. 54) of this report, NUCLEONICS reviews the current status of our national program to harness nuclear energy for space missions. The remaining four sections (see below) summarize the technical progress in principal areas of research and development being conducted under this program.

Harold L. Davis,
Associate Editor

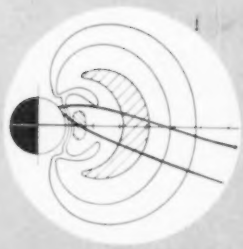
1 NUCLEAR SPACE PROGRAM



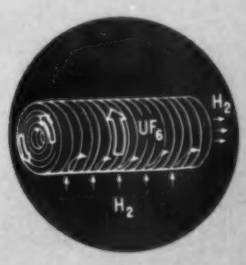
2 POWER SOURCES



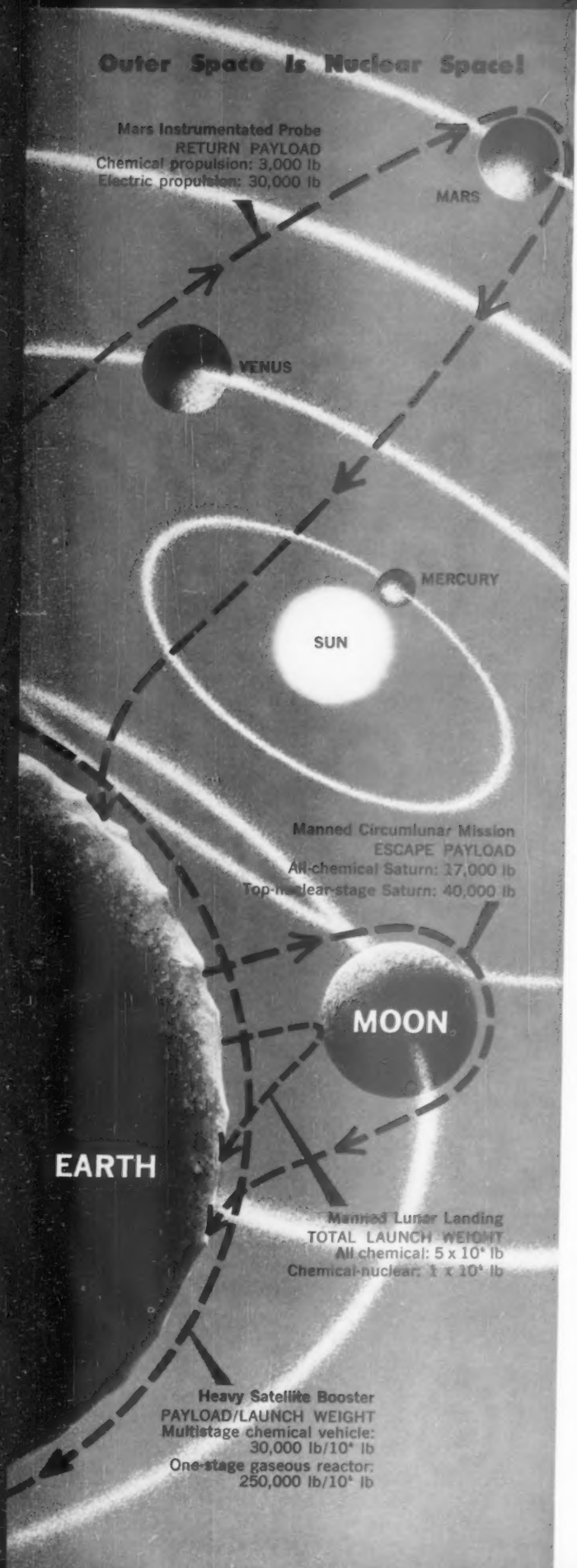
3 NUCLEAR ROCKETS



4 SPACE ENVIRONMENT



5 ADVANCED CONCEPTS



Nuclear

SECTION I—*A major new field of interest is taking shape for the nuclear industry as the planners and directors of our national space effort are beginning to face up to the inevitable need for nuclear*

Washington Foresees

By ROBERT E. L. ADAMSON,

NUCLEAR PROPULSION and auxiliary power are regarded in Washington—where the impetus for their development in the U. S. must come—as both inevitable and essential in the *exploration* and *exploitation* of space. There are arguments over the rate of development of the nuclear rocket, over the economics and safety of nuclear-auxiliary power versus solar power, and—indeed—over the need for a major space program at all. But there is little controversy that, if man is to explore his space "frontier" and make it serve him, as well, he must have the large amounts of propulsive and auxiliary power that only nuclear devices can provide.

Behind these simple statements of the need for nuclear energy, however, are the not-so-simple questions: *when* will nuclear equipment be used and *by whom*? Among the factors that will very much influence both the rate of development of nuclear equipment and its use are:

Safety. Because of both real and psychological aspects of nuclear operations, the statement is heard over and over that "We will not use a nuclear system when we can do the job with something else." There is resistance on the launch pad ("Our rocket firings are already complicated enough without the hazard factor posed by nuclear devices."); there is concern over the public health and the public reaction to nuclear devices in the U. S.; and there is concern that other countries, particularly Russia, will challenge the flying of nuclear devices over their territory and/or the addition of radioactivity to the atmosphere when such devices burn up on re-entry. Safety is not considered a finite obstacle (*see p. 64*) but, rather, a complicating factor possibly entailing delays of application.

Man-in-space Program. The U. S., over recent months, has been debating the financial feasibility and desirability of the presently-planned man-in-space program. Official estimates of the cost of sending man only as far as the moon range from $15–30-billion: some in position of political influence are wondering whether this money would be better spent for earthly projects. The nuclear rocket, in particular, is involved in this debate because the rocket program is principally justified in terms of manned space missions. Thus, officials of the National Aeronautics and Space Administration feel that a retreat or slow-down in this country's man-in-space ambitions could interfere with

Space Program

energy in space. The question now in Washington (see below) is not **will** *we need nuclear propulsion and auxiliary power systems but* **how soon** *will we need them and* **how fast** *should we develop them.*

THE CASE FOR NUCLEAR ENERGY (see left and p. 58) is convincingly argued by NASA for both high-thrust and low-thrust missions and those that require high levels of auxiliary power.

On the often raised question about NUCLEAR SAFETY IN SPACE (p. 64) the AEC offers a detailed strategy of design and operation that would rule out any hazard to local populations.

Major Role for Nuclear Space Power

Associate News Editor, NUCLEONICS

development of the nuclear rocket.

Military Requirement. Another fundamental in the rate of nuclear-rocket development and auxiliary-power utilization is the attitude of the Defense dept., particularly the Air Force and the Navy. At this point, neither military agency has a formal "requirement" for nuclear rockets or auxiliary-power devices (a "requirement" here is government jargon for a decision to get such equipment developed for specific missions). Because the current Rover program, for example, is not thus sponsored by the Pentagon, it inevitably suffers from: 1. the lack of an urgency that only a military need can engender; and 2. the easier flow of development dollars that normally follows a clear-cut military requirement. Both the Navy and AF have industry contractors studying the possible role of nuclear rockets in the defense picture and they will be considering the requirement situation as these studies are completed this year. NASA officials say the Pentagon is free to join the Rover program as a co-sponsor with NASA when it desires to do so.

Basic Policy Differences. Eight days before the Kennedy Administration took over in Washington, a nine-man Ad Hoc Committee on Space reported to the then President-elect John F. Kennedy: "The nuclear rocket program (Rover) presents an area in which some major decisions will have to be taken by the new Administration. In principle the nuclear rocket can eventually carry heavier payloads much farther than any chemical rocket. Nevertheless, the technology is so new and the extrapolation from reactors developed now to sizes which would be useful in large rockets is so great that it is not clear how soon they will make an important contribution to the space program. The use of nuclear rockets will raise serious international political problems since the possibility that a reactor could re-enter and fall on foreign territory cannot be ignored.

"A major technical and management review of the Rover program seems urgent."

The chairman of this preinaugural committee was Jerome B. Weisner, formerly of Massachusetts Institute of Technology and Los Alamos Scientific Laboratory and, since Jan. 20, science adviser to President Kennedy. Because of the essentially conservative tone of these comments, there has been concern in Washington that the new Administration might press for a reorientation of the Rover program—away from hardware and flight-test dates and back toward more basic research-development. Congressional leaders have made it clear they would fight such a move head-on, if it should come; moreover, NASA and AEC have taken the position that early flight test of nuclear-rocket systems is vital to the U. S. space program and that a return to basic work would de-energize the Rover effort. It is clear that there will be a fight on Rover if the Weisner Committee attitude shows signs of making headway within the Administration (see p. 100 for Weisner Committee comments on Project Orion).

Another basic policy difference is this: Sen. Clinton P. Anderson (D-N. M.), former chairman of the Joint Committee on Atomic Energy, has been urging development of the nuclear rocket as an earth-launched booster, rather than an upper stage of a chemical booster such as Saturn. "As I see the nuclear rocket, it is completely independent of Saturn," Anderson insists. This school of thought argues: that the nuclear rocket can make its most important contribution as a several megapound booster; that direct-flight experimentation would be the normal way to proceed and would permit the experimenters to retain a much higher degree of control over the developmental vehicles than in upper-stage flight-testing.

In defending the upper-stage approach NASA argues that it is important to start using these nuclear rocket systems early to gain confidence in their capability and a real appreciation of their potential. As upper stages, the Agency feels, these smaller systems can perform useful missions sooner and pave the way for acceptance of the large nuclear boosters for earth launch. A final factor is that an all-out nuclear booster effort would have to either displace, or compete for funds with, the already high priority F-1 engine program to develop a 1.5×10^6 lb/chemical thrust unit (*see Nova concept, p. 63*).

Project Rover Management

Since last September, when the separate rocket responsibilities of AEC (nuclear) and NASA (nonnuclear) were merged, the program has been managed by Harold B. Finger, director of the AEC-NASA Nuclear Propulsion

Office (NPO). In rough order, Finger's principal activities since then have been: to begin organizing NPO and its suboffices (Cleveland first, then, eventually, Albuquerque); lay out a long range program for the nuclear rocket program; prepare for the entry of an engine-system contractor into the program this year; lay the groundwork for year-by-year construction of the National Nuclear Rocket Test Facility, probably to be located at Jackass Flats, Nev. (NU, Dec '60, 27); and review the rocket program as requested by the new Administration.

NPO is being organized much like the other "two-hat," or dual-agency, offices in the U. S. nuclear program. Finger has offices at both AEC headquarters, Germantown, Md., and a NASA building in downtown Washington. On the AEC side, he reports to Reactor Development Director Frank Pittman; at NASA, he reports to Gen. Don R. Ostrander, director of all launch-vehicle operations. AEC has responsibility for reactor development, with the work centered at Los Alamos; NASA has responsibility for the entire engine system and the vehicle—including control and shielding—with most research-development being carried out at Lewis Research Center, Cleveland. Finger melds these responsibilities under a single manager.

Most NPO personnel under Finger are stationed at Germantown and include: Milton Klein, deputy director; Col. Howard Schmidt of the Air Force (reactor development); Carl Schwenk, engine system (other than reactor); and separate coordinators for safety and test facilities. Schwenk will supervise the work of an industry engine-systems contractor when one is brought into the program to support Los Alamos later this year. Lewis Laboratory was considered earlier this year for a major role in the engine-system design program—that of technical director. But this proposal was vetoed and NPO plans, instead, to establish sub-offices in Cleveland (Lewis) and Albuquerque (Los Alamos) to better coordinate the work of these labs with that of the industrial contractor as the rocket moves toward the design and hardware stages.

Long-Range Rover Outlook

Because Rover is a classified program (anticipating possible military significance), NPO officials cannot discuss their plans as freely as can those working on unclassified projects. However, it is known that a long-range plan has been drawn up which would carry the rocket through flight testing. At this point in the program, it is felt that nuclear upper-stage rockets will be ready for manned circumlunar missions late this decade; for manned lunar landing missions in the early 1970's; and for manned planetary landing missions beyond the moon in the late 1970's. First flight test is now expected "some time after 1965." The major steps in meeting this schedule:

- Develop a reactor.
- Integrate the reactor into an engine.
- Engine-system testing.
- Vehicle development (upper stage).
- Integration of engine into vehicle.
- Integration of upper stage with booster and other chemical stages.

On February 2 of this year NASA and AEC issued an invitation to industry for proposals on "research and development of a nuclear-rocket engine [Project Nerva]." The invitation was issued after NPO had disclosed last fall that Rover would be speeded up by bringing in an engine-systems contractor earlier than had been anticipated. The invitation finally issued in February, however, was a cautiously-worded one covering only an initial phase of the engine-development program: support for Los Alamos in the Kiwi-B tests, preliminary design of a flight engine and certain research-development on non-nuclear components.

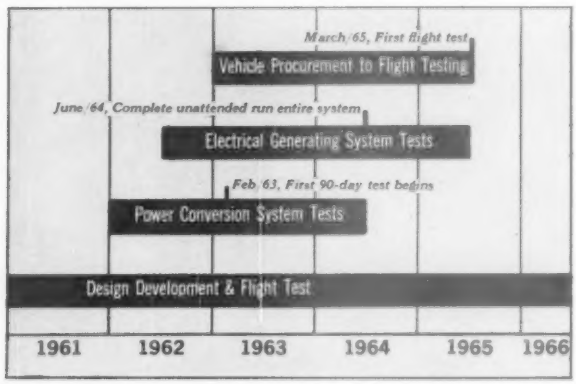
Though only a first-phase contract will be awarded, the contractor will be selected on its "capability to carry out the entire nuclear-engine development program." The reason for "phasing" in the engine contractor was this: AEC and NASA could not agree on assigning engine-development to a private firm at this point in the program. Thus, the firm will be brought in early this year but will not be given a full role until some future date. Proposals in response to the February invitation were due Apr. 3.

Flight-test Studies

In recent weeks, four firms—Lockheed Aircraft Co., Martin Co., Douglas Aviation and Convair Astronautics—have submitted to NPO their ideas on the problems of flight-testing nuclear systems and how these problems might be met. These studies put NPO in position to take its first hard look at such questions as: what vehicle configuration should be used in a test program? where should flight tests be conducted? what types of rocket "shots" make sense (ground launch, lob firings, orbital start-up)? and what type of information should be sought in terms of an operational system?

Known as the RIFT studies (Reactor In Flight Test), these are also expected to give NPO some useful data on vehicle and stage design, cost estimates of the development program and safety. The study groups were asked to concentrate on technology reflecting the current Rover program and—in proposing particular systems—to "lay out all the problems" in flight-testing such systems. The RIFT data is expected to be of substantial influence on the course of the development program.

First flight-test systems, it is anticipated, will likely use reactors of about 1,000-Mwe. The subsequent moves to higher powers will be step-wise and will come only after every feasible step has been taken to improve the power densities of each particular system. "We will use the same systems over and over, improving the technology to get to high-power density," an NPO official explains, be-



SNAP-8 SCHEDULE calls for flight test in March 1965 of a 30–60-kwe reactor feeding power to two electrical propulsion engines

fore moving on to the next logical higher-power system.

NASA's Marshall Flight Center is expected to have responsibility for integrating chemical-nuclear vehicles and flight-testing, as it has had for all-chemical vehicles.

Informed observers report that the rockets to be developed on the present schedule will use solid-core graphite reactors. Other core materials and more advanced concepts (gaseous cores, etc.) are under study at Los Alamos, Lewis and in industry for development on a post-graphite basis. Molybdenum is an interesting next-step material for solid-core reactors but the most promising is tungsten, particularly its low-neutron absorbing 184-isotope. The technology is somewhat behind graphite, however, and the requirement for enriching natural tungsten to get useful quantities of the isotope raises economic questions.

National Nuclear Rocket Test Facility

A companion program to engine development is that calling for construction over a period of about five years of the National Nuclear Rocket Test Facility (NNRTF); site has not been finally determined but NASA-AEC would like to have it at Jackass Flats, Nev., where the Rover reactors have been tested to date. Funds are available for a design study—now being carried out by the Ralph M. Parsons Co. and a four-company group known as Talant—and for architect-engineer design work. Funds will be requested for the facilities themselves as they are needed. The facility is intended to provide all of the test stands, liquid-hydrogen storage tanks and other equipment to be needed for remote firing of nuclear rockets. Total cost is estimated at something under $100-million. NNRTF, according to present plans, would be used for static firing only; flight tests would be conducted at coastal points.

SNAP-8: First Space Reactor?

In a business where the future is either secret or uncertain—that is, the use of nuclear equipment in space—NASA's SNAP-8 program (with AEC offering technical advice) is a breath of fresh, clear air. First flight test has been scheduled, the steps leading up to this test have been defined and scheduled (*see graph, page 56*), and the responsibilities of all who must contribute to meeting the schedule have been assigned.

If all targets are met, an Atlas-Centaur vehicle will be launched from Cape Canaveral in March of 1965 carrying in its nose two developmental electrical propulsion systems of 30 kwe each, powered alternately by a 30-kwe reactor (the hope is, however, that a 60-kwe reactor will be available). The "payload" will go into orbit 300–600 mi out into space, stay in this orbit only long enough to assure that a stable orbit has been achieved, then spiral in an ever-increasing orbital path away from earth until it "disappears" into outer space. It will have equipment aboard to report on: temperature conditions of the reactor's mercury turbine vapor; leak integrity of the system (meteoroid penetration); system endurance, or life-time; and performance of the ion and arc-jet engines providing the electrical propulsion.

The "team" brought together to create SNAP-8 includes: NASA itself (system sponsor and development manager for the ion and arc-jet propulsion systems); NASA's Jet Propulsion Laboratory in California (mission requirements); Lewis Laboratory (technical director for system development); AEC (reactor development adviser to NASA); Atomics International (reactor contractor); Aerojet-General Corp. (contractor for entire reactor system, including conversion machinery); and Marshall Flight Center (flight-test manager). Principal NASA contractors for development of the ion and arc-jet engines are: Lewis Laboratory (mercury ion engine); Hughes Aircraft Corp. (cesium ion engine); and General Electric Co., Plasmadyne Corp. and the team Avco-RAD Laboratory, all developing arc-jet engines. In the fall of 1962, NASA expects to flight-test the first of these ion and arc-jet engines in 500-watt sizes; a year later, using batteries for electricity feed, flight-test of 1-kw engines will be carried out. Then, in the spring of 1965, nuclear power will be used for the first time—to feed 30-kwe engines designed to deliver specific impulses of 5,000 sec.

The NASA goal is electrical-propulsion systems of at least 1 Mwe (NU, Feb. '61, 82) to permit specific impulses of 20–60,000 sec—before the end of this decade.

Auxiliary Power

Earlier in this article, attention was called to the nearly universal feeling among government officials that "We will not use a nuclear system in space if we can do the job with something else." It is the consensus of space experts that this "something else" will not be available for: **1.** high-power requirements—from several hundred kilowatts up; **2.** missions in lower power ranges where sunlight is cut off or where power supplies must be particularly rugged, such as a planetary impact of instrument systems; and **3.** long-life (5–20 years).

Large Power Requirements. It is too early in the space era to state conclusively that hundreds or thousands of kilowatts of auxiliary electricity will be required for orbital and deep-space missions. Some scientists, for example, feel that constantly improving electronics technology will hold down the need for electricity to the few-kilowatt level for many years. Others, however—and these are in the majority—share the opinion of a scientific adviser to the Defense dept.:

"We have a lot of homework to do in space vehicles before we try to assign power supplies. However, when we get there, we must have the power ready. We always seem to end up needing more power."

Thus, in addition to NASA's electrical-propulsion program aiming for 1-Mwe reactors, the Air Force has had Aerojet-General and AiResearch div. of Garrett Corp. conceptually studying 300–1,000-kwe reactors (NU, Feb. '61, 83), and AEC, in its SNAP program, is hoping to reach the 1-Mwe power level with its zirconium-hydride reactor-core technology.

Special Missions. In the low-power ranges—from a few watts to 30 kw—both reactors and radionuclide generators will have a place. NASA's Jet Propulsion Laboratory, for example, would like to use a 15-watt, curium-242 generator in the Surveyor project (soft landings on the Moon, beginning in 1963, of 250 lb of instruments and 500 lb of communications equipment for reporting on ambient and surface conditions). Martin Co. is to complete a feasibility-safety study of such a device this June, then NASA and the Surveyor contractor, Hughes Aircraft, must decide whether to use a radionuclide system—or solar or fuel cells with batteries.

The Case for Nuclear Energy

THAT NUCLEAR ENERGY IS ESSENTIAL to the long-range picture of space exploration, everyone is quick to agree. Potentially the nuclear rocket offers order of magnitude improvements in performance over chemical systems for the interplanetary missions of the future. Not so widely appreciated, however, is the fact that essentially the same nuclear engines that will be required for these long-range missions could give us factors of two to three in performance advantage for missions we are thinking about now—sending a man around the moon or landing one on the moon's surface. Even early models of electric propulsion systems powered by nuclear devices when developed and applied to combined communication-propulsion missions would outperform the all-chemical Saturn vehicle on certain interplanetary missions.

However, an aggressive and urgent program is essential if we are to enjoy, to the fullest, the advantages that nuclear systems can offer for many of the missions we have in mind. Going from research data through "nuts and bolts" engineering to the developed system takes such a long time for space vehicles, that we must recognize space-program requirements very early to allow time to gather the research information necessary for system development. This is a lesson we learned in our chemical rocket program (see box).

The requirements of the long-term space program clearly indicate that nuclear energy will be necessary for "real" space operations. The AEC-NASA program for developing nuclear rocket systems and our program to develop nuclear-electric power generating systems both aim at establishing the technology that will be required for these nuclear systems to perform the many possible missions for which they are well suited. An integral part of this program is flight testing of systems at the earliest feasible time.

In this article I discuss only nuclear rockets and electric-power generating systems because I believe they are further advanced in concept and in experimental results than are the other fission energy systems (gaseous core, Orion, etc.) that have been proposed. The early tests in both of these programs have been extremely encouraging.

AUTHOR

***Harold B. Finger** is Asst. Dir. for Nuclear Applications in NASA's Office of Launch Vehicle Programs and is Manager of the joint AEC-NASA Space Nuclear Propulsion Office, responsible for nuclear rocket propulsion. Finger has held his NASA job since the organization was set up in 1958; previously he was a research scientist with NACA.*

NUCLEAR ROCKETS

The performance advantage of the nuclear rocket lies in its high specific impulse—two to three times the impulse possible with chemical systems. This high impulse means that potentially the nuclear rocket can accomplish a given mission with a smaller amount of propellant so that the ratio of dry weight to gross weight for the system can be larger. Although some of this dry weight is taken up by the extra weight of the nuclear propulsion unit, the greater dry weight can make possible significant increases in payload for nuclear systems compared with chemical ones on many missions of interest.

To make any quantitive statements about payload advantage we must consider specific missions. Let us examine the requirements for three representative missions:

- Manned circumlunar mission
- Manned lunar landing mission
- Manned planetary landing mission.

The missions are ranked in order of increasing technical difficulty. The first two are defined objectives of the NASA space program; the circumlunar mission should come to pass within the decade and the lunar landing mission is now planned for early in the next decade. The Mars mission is representative of the space explorations we may be undertaking in 20 years or so.

For each of these missions we have compared the performance of an all-chemical propulsion system with that of a chemical-nuclear system or all-nuclear system. The

A Lesson in Lead-Time

The start of the space age found the U. S. working on IRBM, ICBM and Vanguard vehicles, no combination of which could lift the payload carried in 1957 by Sputnik I. Fortunately, an extensive research program on hydrogen as a fuel for aircraft and hydrogen-oxygen as a propellant-oxidant combination for rocket propulsion had been in process for several years, principally at the National Advisory Committee for Aeronautics (which formed the nucleus of the National Aeronautics and Space Administration when it was set up in 1958). This information formed the basis for a hydrogen-oxygen rocket development, the Centaur project (see box, p.63), which was rushed into being in 1958. When the Centaur stage makes its first flight sometime later this year, the U. S. will for the first time have a payload capability comparable to that already demonstrated by the Soviet Union (although still smaller by a factor of two than the recent Soviet 7-ton shot). In spite of the fact that we started with a large fund of research knowledge, over three years will have elapsed between the start of development and the first Centaur flight.

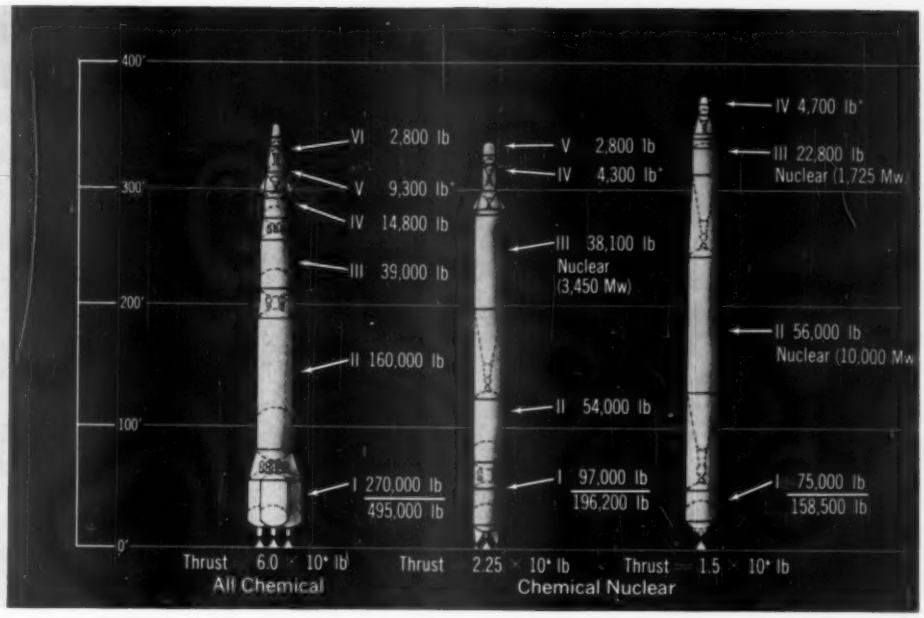


FIG. 2. MANNED LUNAR LANDING vehicle configurations compared for all chemical stages (left) and both chemical and nuclear stages (right). Each system would return 8,000 lb re-entry vehicle to earth. Weights shown for stages to hardware and unused propellant only. Weights marked by (*) include 1,300 lb left on moon. Chemical-nuclear systems can perform mission with only 25% of thrust needed by all chemical system.

assumptions made in these comparisons about the space environment and mission requirements were the same for all systems.

The vehicle configurations shown do not result from detailed mechanical design analysis. These analyses will certainly influence the actual vehicle configurations and payloads achieved but their effects are not expected to alter significantly any of the results given here. In particular they will not alter the main conclusion of the subsequent analyses: that even the early versions ot the nuclear rocket have impressive advantages for a wide spectrum of space missions—not only the high-payload, high-energy missions of the more distant future (for which the advantages of nuclear propulsion are already widely recognized) but also the less ambitious missions of the nearer future.

Manned Circumlunar Mission

Vehicles of the advanced Saturn class (see box, p. 63) would be required to perform the manned circumlunar mission. The escape payload of an advanced three-stage Saturn vehicle is 15,000 lb. On the basis of what we can now foresee about the control requirements, space radiation problems, ecological systems, power supplies, communications, thermal shielding, etc., this payload appears just sufficient to perform the mission with an Apollo spacecraft.

However, at this early point in our program we are less than certain of the payload demands that will be imposed by the space environment and by the technology of guidance and flight mechanics. For instance, should the solar flare radiation dose be more severe than expected or should we fail to learn how to predict solar flares by the time the mission is ready for launching, an increased payload margin for additional radiation protection may be required to carry out the mission.

If we limit ourselves to fitting a manned spacecraft for this mission within the 15,000-lb payload capability of the Saturn, then we may run the risk that we will not be able to perform the circumlunar mission on the desired time schedule. In my personal opinion, the nuclear rocket program should aim toward developing a nuclear stage as a third stage on an advanced-Saturn two-stage chemical vehicle. The increased payload possible with the nuclear stage would provide insurance for the manned circumlunar mission. In the development and operation of such a stage we would also be getting a head start in accumulating the operating experience on nuclear stages that we will need to use these systems on later, more difficult missions.

Figure 1 compares the performance of a nuclear Saturn vehicle (a nuclear stage on top of two chemical stages), with an all-chemical advanced Saturn vehicle* for a circumlunar mission. The payloads shown do not include biological shielding for space radiation or reactor radi-

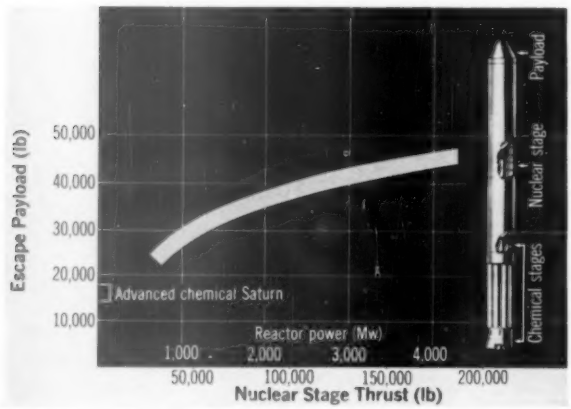


FIG. 1. NUCLEAR STAGE ON SATURN would lift escape payloads (shown vs. reactor power) twice that of all-chemical Saturn

* W. Y. Jordan, et al., Nuclear rocket stages increase Saturn's payload capability, Annual Meeting Institute of Aerospace Science (New York, 1961).

ation (see p. 110). The latter has been estimated at approximately 2,000 lb if no space-radiation shielding is provided. From the figure we can see that a payload of two to three times the payload of the all-chemical Saturn can be delivered if the third stage is replaced by a nuclear stage. A detailed design analysis of bending moment limitations in Saturn vehicle configurations might limit the reactor power to values on the curve below the maximum shown. The design of the first two stages can be the same for both the chemical and nuclear alternatives if the nuclear application is considered in early development.

The present reactor development program at Los Alamos will provide information on reactors of the type that have been considered in this mission analysis.

Manned Lunar-Landing Mission

Among the approaches proposed for manned lunar-landing mission are:

- Assembly and/or fueling of a spacecraft in orbit
- Direct flight from earth to moon with an all-chemical system
- Direct flight from the earth to the moon with a combination of chemical and nuclear stages.

The Marshall Space Flight Center is carefully evaluating all of these approaches.

I have not included in this list the all-nuclear system that would take off from the earth, land on the moon and take off from the moon. Many technical problems must be considered and solved before such a system could be used. One of these is the problem of how men could exit from a nuclear vehicle landed on the moon after the reactor had operated at full reactor power. In addition, there is the problem of contaminating the take-off or landing site in the event of a mission abort. Moreover, the large-reactor power levels required for an all-nuclear system imply longer lead times than we can tolerate for the manned lunar-landing mission.

The orbital take-off approach assumes that a single Saturn places the entire spacecraft excluding the propellant into an earth orbit. Additional Saturns then carry the propellant to the orbiting vehicle and refuel that vehicle in orbit. In this concept the orbiting vehicle could be a nuclear stage that would serve as a reusable earth-orbit to moon-orbit ferry. The orbit take-off weight could be much less than for an equivalent chemical system. Because the vehicle is started in orbit, the thrust and, hence, the reactor power could be low. A thrust to weight ratio as low as 0.2 at a specific impulse of 800 sec could be tolerated without suffering severe penalties in payload. At this impulse 1 Mw of reactor power would be needed for each 50 lb of thrust required. A fully loaded orbital vehicle weighing 200,000 lb could, therefore, be propelled by an 800-Mw reactor.

In the opinion of many, a quicker and easier approach would be the direct flight system in which the rocket takes off from the earth, lands on the moon and returns the spacecraft to earth. Although the payload needed for the manned lunar landing is not yet specified, it has been estimated that the earth escape payload would have to be 150,000–250,000 lb. This escape payload assumes that the return vehicle will be propelled by a storable propellant-chemical rocket system. In general, for the escape payload mentioned, the spacecraft returned to earth would weigh in the neighborhood of 8,000–15,000 lb.

Many vehicle configurations have been and are being studied for this approach at the NASA field centers and by industry. Figure 2 presents some configurations calculated at the Lewis Research Center. For a re-entry spacecraft of 8,000 lb, Fig. 2 compares an all-chemical vehicle with two vehicles that use both chemical and nuclear stages. In all of these vehicles the first stage uses kerosene and liquid oxygen as the propellants. All other chemical stages in the vehicles burn hydrogen and oxygen. The reactor power of the liquid-hydrogen nuclear stages is indicated on the figures.

The chemical-nuclear systems are from one half to one third the weight of the all-chemical system. Comparisons of larger systems capable of returning a 15,000 lb spacecraft show similar savings for chemical-nuclear vehicles. In addition, since the nuclear systems have at least one less stage than the all-chemical system, they could be more reliable than the all-chemical system. As an indication of vehicle cost, consider the system weight data shown in Fig. 2. The total hardware weight is approximately 495,900 lb for the all-chemical system compared with 196,200 and 158,500 lb for the two chemical-nuclear systems. This lower manufactured weight of the nuclear systems suggests that the cost of the chemical-nuclear vehicle will be significantly lower than the cost of a chemical vehicle, even though the nuclear engine itself may be more costly than a chemical engine.

Planetary Missions

It is in distant planetary missions requiring high payload that the nuclear rocket shows its greatest advantage and its long-term justification. For example, a three stage orbital-start vehicle to take a manned expedition to Mars and return it to earth would, if propelled by chemicals, have a calculated initial total weight of 9,100,000 lb. An orbital vehicle composed of three nuclear stages (10,900 Mw, 6,160 Mw and 1,890 Mw) could do the same job with an initial total weight of 935,000 lb—a factor of ten less.* These calculations are obviously preliminary in nature and based on gross assumptions regarding the life-support requirements for men, the requirements of guidance and control equipment to permit a successful planetary flight, space shielding requirements, etc. The vehicles will have to be assembled in orbit using large booster vehicles. (One would expect that a vehicle developed for the direct-flight-manned lunar landing could carry the parts of these orbital-start planetary vehicles to the orbital assembly point.) The reactor powers for these planetary vehicles fall within the same range as those of the nuclear-manned lunar-landing vehicles (Fig. 2.) It is entirely possible that comparatively low-power (but high power density) reactor systems as basic units could be clustered to provide the high power levels we foresee in the lunar-landing vehicles. These same basic reactor engines could then be rearranged into configurations appropriate for planetary missions.

The clustering of basic engine units would require separate development programs but such programs should be far less costly than the programs to develop completely

* Based on the assumptions and results quoted by Himmel, et al. A study of manned nuclear-rocket missions to Mars, Annual Meeting Institute of Aerospace Sciences (New York, 1961).

new engines even though the technologyis available.* It is important to recognize this long-term applicability of a particular nuclear-rocket engine development. For this reason the development of the nuclear rocket should not be charged to any one mission. Its broad applicability in the space program indicates that its research and development costs may be amortized over several applications and over many missions.

Conclusions

In summary, the nuclear rocket clearly offers major advantages in its ability to perform planetary missions. It provides an order of magnitude improvement in performance and promises substantial improvements in reliability. It makes possible a payload margin that permits maneuverability, added safety features, and, in general, increased freedom to travel in space.

Propulsion systems intended for interplanetary missions may be reasonably applied first to the lower-energy increment, shorter-range missions to the moon. For these earlier missions, nuclear rockets offer the advantages of one-half to one-third the gross weight of the chemical systems along with the increased reliability of fewer stages.

The large number of potential applications for nuclear rockets and their large performance potential should be sufficient justification for an aggressive program designed to give the United States the technology to pull ahead and stay ahead of the Soviet Union in the space field. The quantum jumps in our program that would be afforded by an operational nuclear rocket would provide a major advance in our nation's technological stature in the world.

Research and Development

Although the three reactor experiments, conducted by Los Alamos in the KIWI-A series (see p. 77), have supplied very useful and promising information, several important unknowns remain regarding the reactor component. The two principal questions that require further answers and information are:

- Structural integrity of the reactor at the high-temperature, high-power density operating conditions required
- Start-up procedures for the flight reactor system.

The temperature levels desired in the nuclear-rocket reactor (above 3,500° F) are higher than those experienced in any reactor system that we know of. Chemical reactions may be expected at these temperatures and the strengths of materials must be carefully utilized. However, our hope is that the comparatively short operating time (10 min to an hr) required of this reactor may ease the difficulties normally anticipated at such high temperatures.

Less information is available about automatic start-up procedures for nuclear-rocket reactors. The procedures developed will represent a compromise among flight-vehicle requirements, and reactor thermal shock and dynamics considerations (see p. 80).

If short start-up times (less than a minute) are not possible, then it may be necessary to start the nuclear stage before a previous stage has burned out. This will require vehicle configurations that allow stages to fire in parallel rather than the familiar series configurations.

Krafft Ehricke has studied such a configuration (Helios).*

* K. Ehricke, JCAE Hearings, Frontiers in Atomic Energy Research, March 1960.

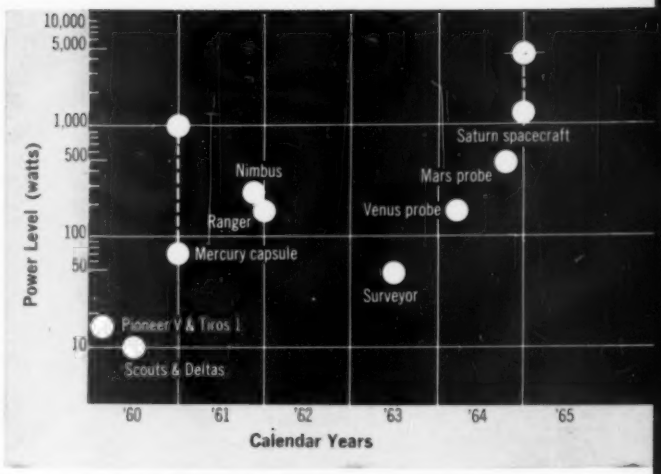


FIG. 3. ELECTRIC POWER REQUIREMENTS estimated for space missions shows two orders of magnitude increase over 5 year period. Dotted lines connect upper and lower limits

Aside from these major reactor questions, the research and development areas for the nuclear rocket are similar to those for chemical-combustion rocket systems with the effects of nuclear radiation, liquid-hydrogen temperatures, and high heat fluxes superimposed. Hydrogen pumps that have a higher capacity than any now available will be required and pump cavitation limits may be significantly affected by the radiation field of the reactor.

The jet nozzle will experience heat fluxes 50–100% greater than the heat fluxes experienced in chemical-combustion rocket engines. If satisfactory cooling cannot be provided, insulation coatings or erodable nozzles may have to be developed.

Radiation effects on the properties of structural materials may be severe at the low liquid-hydrogen temperatures where annealing effects are small if at all noticeable. Methods to integrate and control the total propellant impulse of the vehicle must also be developed. Thrust vector controls will be required.

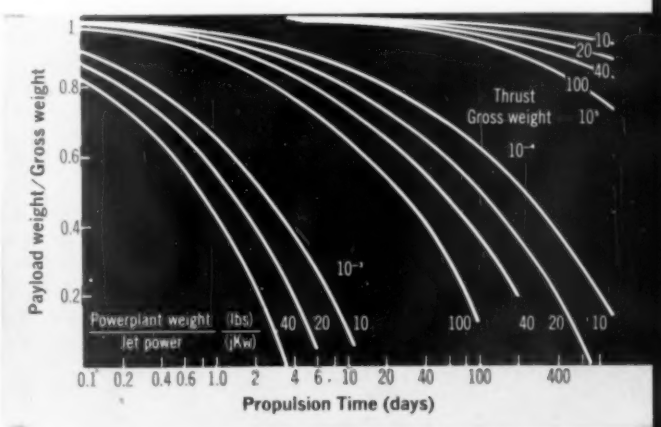


FIG. 4. LOW-THRUST SYSTEM PERFORMANCE based on optimum impulse at constant thrust for electric propulsion systems

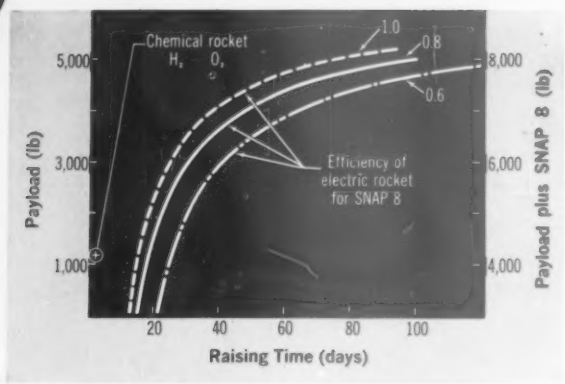


FIG. 5. PAYLOAD RAISED TO 24-HR ORBIT by SNAP-8 electric propulsion unit versus raising time. SNAP-8 capacity is up to five times that of chemical stage. Comparison assumes both units start from 300 mi orbit with initial weight = 9,000 lb

In addition, the flight testing of a nuclear rocket system will provide important data in these areas of controllability, flight dynamics, vibrations, automatic start-up, etc.

ELECTRIC-POWER GENERATING SYSTEMS

In addition to the propulsion of advanced vehicles, nuclear energy can supply the electrical power needed to operate the equipment and instrumentation included within space payloads. Nuclear systems that generate electric power could also provide the power for the electrical propulsion devices that are now in the research and development phases.

Auxiliary Power Systems

The estimated requirements for auxiliary electrical power are presented in Fig. 3 as a function of the time at which the mission is to be conducted. Non-nuclear power supplies of the type already in service such as chemical batteries or silicon-solar cells with battery storage, can supply the power requirements for many of the early low-power missions. But levels of auxiliary power in Saturn spacecraft will extend to approximately 5 kw(e) in 1964. Higher auxiliary powers can be anticipated for the vehicles that will follow Saturn, e.g., the chemical-nuclear lunar landing vehicle discussed earlier. Improvements in electronics may reduce the power needed to perform specific tasks, but the pressure to accomplish as many things as possible on a given mission will motivate designers to use all the auxiliary power available.

This trend toward higher power levels will require the designer to turn to nuclear power systems. At power levels above 10–30 kw(e) nuclear reactor power systems promise to be lighter in weight than any other power generating system.

Even for the low power range, when long life is required isotope power supplies may be the answer and offer the further advantages of light-weight, compact and rugged design. These systems have been under development by the AEC for several years to meet a number of needs by the Air Force and Navy. Because of the advantages of isotopic power devices, the NASA has asked the AEC to evaluate the feasibility of developing a 15-w radioisotope thermoelectric power system (similar to the AEC's SNAP-3 concept) for the soft lunar landing experiments to be started in 1963. For this lunar mission, with its "14-day" night, a nuclear powered system has marked performance advantages over the alternative of heavy storage battery systems coupled with silicon-solar cells.

Propulsion Systems

In addition to the auxiliary requirements, electrical power in very large quantities will be needed for the electric propulsion systems now under study. The feasibility of electrical propulsion depends primarily on the development of very light-weight long-life electric-power generating systems. Only with nuclear energy does it appear possible to achieve sufficiently light-weight systems. Figure 4 demonstrates the importance of lightweight in these systems. The ratio of payload to the orbital weight of the spacecraft is plotted against the powered flight time for thrust to orbital weight ratios of 10^{-3}, 10^{-4} and 10^{-5} and for various values of specific power plant weight (pounds of power plant divided by the jet power in kw). The thrust to weight ratio is the acceleration in "g's" that exists at initial orbital startup of the electrically-propelled vehicle.

These data apply to any mission. Integration of the energy equation determines the time required to supply the energy needed to achieve a particular mission. For example, if we were to leave an earth orbit and go out to orbit Mars and then return to the earth orbit, we would have to travel approximately 500 days of powered flight for the minimum energy trip with an initial thrust to gross weight ratio of 10^{-4}. The total trip time for such a mission would be in excess of 1,000 days. From Fig. 4 we see that the power-plant specific weight for this long-range mission must be below approximately 20 lb/kw to deliver significant payloads. At this performance level, for instance, a 150,000-lb vehicle starting from an earth orbit to circumvent Mars could return 30,000 lb back to earth if propelled electrically, compared to 20,000 lb for direct nuclear propulsion and 3,000 lb for chemical propulsion.

The ion propelled mission will, however, take a longer time, which means that the propulsion system must have a long operating life. Long-range missions for which electrical propulsion is intended will generally demand system lifetimes in excess of a year. The two requirements of light weight and long life impose severe problems in the development of electrical propulsion. As I will point out, some of these problems can be evaluated only in the space environment. Flight testing is, therefore, essential to establishing the feasibility of nuclear electrical propulsion.

System Development

Various analyses by industrial and governmental organizations show that to attain specific weights of 20 lb/kw or less, designers must look to high-temperature (~2,000° F), Rankine-cycle turbogenerator systems or, possibly, high-temperature thermionic emitter systems. Although many groups have demonstrated the conversion of thermal power to electric power output with thermionic emitters, these systems are still in the early research and development phases. I shall, therefore, concentrate on the turbogenerator systems. The emphasis on high temperature results from the fact that the waste thermal

energy of the conversion cycle must be rejected through a radiator which, in the many kilowatt power range, becomes the largest and the heaviest component of the system. The radiator area is inversely proportional to the fourth power of the radiator temperature. For the same maximum cycle temperature, the radiator area for the Rankine-cycle system is an order of magnitude smaller than that for the gas Brayton cycle. This is because the heat of vaporization in the Rankine cycle is rejected at the maximum cycle temperature while in the Brayton cycle the average radiator temperature is well below the maximum cycle temperature.

Protection of the large areas of thin-walled radiator flow passages from meteoroid penetration introduces a weight penalty that increases at a faster rate than the radiator area because of the higher probability of penetrating a larger surface. In estimating protection needs, so far we have had to depend on penetration models worked out on the basis of analytical studies and experimental studies of particle penetration at much lower velocities than those of meteoroids. The validity of these low-speed models can be checked only by space experiments or system flight tests. In addition flight tests will be required to evaluate the effect of zero gravity in fluid flow.

The need for light weight and the resulting emphasis on the high-temperature Rankine cycle highlights the importance of extending the technology of liquid metals and metal vapors to temperatures up to ~2,000° F. Although data exist for the alkali metals to 1,500° F., there is very little information at higher temperatures on the thermodynamic and transport properties, boiling and condensing heat-transfer characteristics and corrosion characteristics (in familiar container materials) of fluids such as sodium, potassium and rubidium. Fabrication difficulties can be anticipated with these fluids at the temperature levels of interest. The choice of materials will require research and extensive testing. The operation of turbines, pumps and generators at these temperature conditions must be evaluated. Until this information is available, we can not logically start to develop or even design the hardware of high-power nuclear-electric generating systems. For this reason, NASA is initiating a vigorous program to provide the fundamental information required prior to major hardware development. The AEC and the Air Force are also evaluating certain of these unknowns.

All of the areas mentioned above are being or will be studied by government organizations, non-profit organizations and industrial organizations.

Our program on high-power nuclear-electric generating systems is, therefore, aimed at providing the fundamental data required to establish the feasibility of these systems.

SNAP-8 Program

The ultimate objectives of electrical propulsion relate to long range missions to the distant planets by high electrically-propelled vehicles boosted into orbit by large launch vehicles. However, before this time comparatively low-power nuclear-electric generating systems such as the SNAP-8 can provide needed power for many useful missions.

Supported jointly by the NASA and the AEC, the SNAP-8 development uses the reactor technology being developed by the AEC for SNAP-2. We look to SNAP-8 to provide sufficient electric power to permit us first, to evaluate the feasibility of electrical propulsion and, then, to give us the capability of performing useful missions that can use electric power both for communications and propulsion.

For example, Fig. 5 shows the payload that could be raised from a 300-mile orbit to the 24-hr orbit by a spacecraft powered by the 60-kw version of the SNAP-8.

The payload propelled by the SNAP-8 is significantly larger than the payload that could be delivered with a hydrogen-oxygen chemical rocket stage that started with the same initial weight from the 300-mile orbit. Once in the 24-hour orbit, three carefully placed SNAP-8 systems could provide television channels for a world-wide commerical network that could be received on any TV set equipped with an inexpensive VHF converter. On a Mars orbit mission a 60 kw(e) SNAP-8 could supply power to an electrical thrust generator to propel a spacecraft placed in orbit by a Centaur vehicle. The combination of the Centaur and the SNAP-8 propelled spacecraft could (after the SNAP-8 is developed) deliver as much payload weight to Mars as would be possible with the Saturn vehicle now under active development at the Marshall Space Flight Center. The payload weight would not include the weight of the SNAP-8 system itself which could provide auxiliary power at Mars.

I must emphasize that the technology is available now to develop the Saturn vehicle. The Saturn payloads presented in the earlier charts are considered to be accurate and attainable through the active development program now in process at the Marshall Space Flight Center. In contrast, the SNAP-8 payloads I have presented assume that certain questions about liquid-metal systems—the long-life, orbital start, zero-gravity boiling and condensing, meteoroid penetration and others—will be resolved satisfactorily. The work on electric power systems is at a much earlier point of development than the Saturn work; the present program aims first at demonstrating feasibility. Firm space missions, therefore, cannot yet be scheduled for an electrical propulsion system.

NASA's Timetable for Chemical Boosters

Vehicle	Payload weight (lbs) Earth orbit / Escape	NSA Timetable 1st Launch	Operational	Height* (ft)	Total no. of Stages	1st stage total thrust (lbs)	Remarks
Scout	150/—	'60	'62	65	4	103,000	All solid fuel stages
Thor-Agena B	1,600/—	'62†	?‡	86	2	165,000	will replace Delta vehicle
Atlas-Agena B	5,000/750	'61	?‡	89	2	360,000	Agena B will restart in space, after coasting
Atlas-Centaur	8,500/2,500	'61	'63	105	2	360,000	2nd stage, first use of liquid H_2O_2 engine
Saturn C-1	19,000/5,000	'61	'64	150	3	1,500,000	1st stage, first engine cluster (eight Atlases)
Nova (concept only)	290,000/approx. 100,000	'68	?	240	up to 5	approx. 9,000,000	probable cluster of six F-1's (1.5 x 10^6 lb each)

* Less payload. † Army date is '61. ‡ Proof test series not yet fully budgeted.

Nuclear Safety in Space

AUTHORS

Brig. Gen. Irving L. Branch, USAF, *is Chief of the Aircraft Nuclear Propulsion Office (a joint AEC-USAF office). He is also Assist. Deputy Chief of Staff/Development for Nuclear Systems, USAF and Assist. Director for Aircraft Reactors in the AEC's Div. of Reactor Development. Previously he was Deputy Commander of the Air Force Special Weapons Center.*

Lt. Col. Joseph A. Connor, Jr. USAF *(MC) is the Chairman of the Aerospace Nuclear Safety Board, a 12 man group set up within the Div. of Reactor Development in 1959 to ride herd on AEC's varied investigations of nuclear safety in space. He brings to this job a medical degree plus 18 years of varied responsibilities in Air Force medicine.*

THE THREE BASIC SAFETY objectives officially adopted by the Aerospace Nuclear Safety Board for all nuclear space systems (SNAP isotope and reactor units and Rover propulsion units) aptly sum up the safety problems posed by the launching and operation of these systems (see Fig. 1):

- Under the most adverse conditions, these devices should not add materially to the general background of radioactivity in the atmosphere (e.g., not more than 1% or 2% of background, over a continental or broad ocean area)
- During the operation of these devices at a launch pad, operational base or test range, all harmful radiation should under any circumstance be contained either within the device itself or within the prescribed exclusion area
- On return to earth, the devices should not create a local hazard for people who might happen to be in the area.

The first two problems are already well in hand. The radioactivity that could be released by nuclear powered devices sufficient to meet all the space requirements foreseeable by 1980 would, if uniformly dispersed, make a minor contribution to the world background level. Calculations show that our present two test-launching sites (Cape Canaveral, Florida and Vandenberg Air Force Base in California) could handle the maximum credible releases from both SNAP and Rover systems.

The solution to the problem of random re-entry requires further investigation and testing. But, through special design features and devices that promote fast burnup, we expect to be able to guarantee the complete burnup of nuclear-powered vehicles that might fall outside our flight range areas (see Figs. 1 and 2).

If we are successful in this latter aim then the radiation risks associated with nuclear space systems should be no greater than, and usually much less than, the risks encountered in the development of other technological advances such as electric power, the airplane or chemical rockets. The added operational costs to achieve this protection, though admittedly high, can be kept within reason.

Once the safety of nuclear space devices is firmly established we can look ahead to the day when nuclear space power will be commonplace rather than extraordinary. By that time, an international accord on the registration and regulation of these nuclear power sources may be necessary. It is not too early to give thought to this requirement of the future.

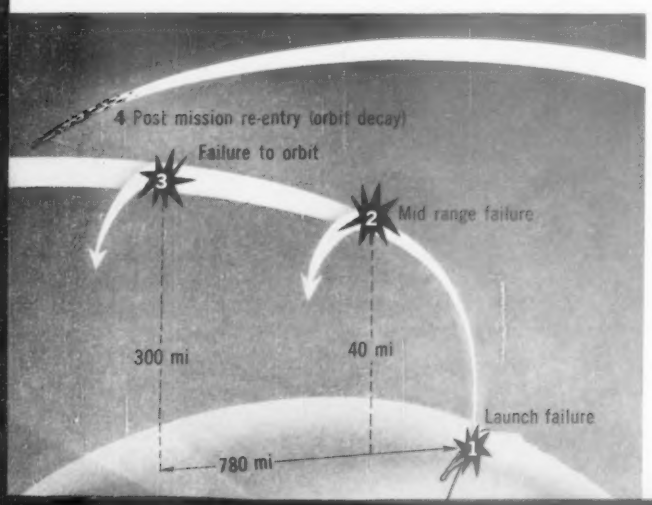


FIG. 1. VEHICLE FLIGHT PHASES. Hazards from phases 1 and 2 would be confined to test range; complete burnup of nuclear space system upon reentry would eliminate any radioactive hazard to local populations from phases 3 and 4

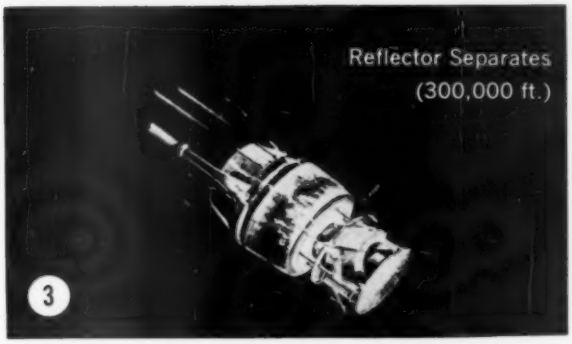
The Problems

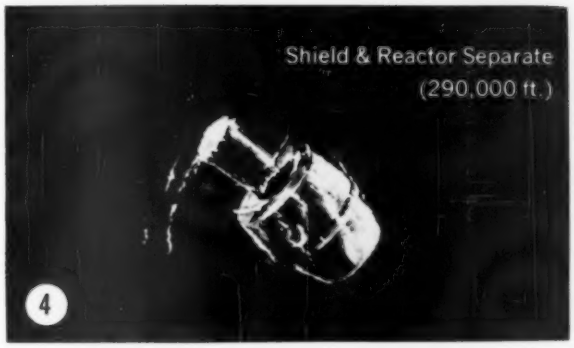
The possible hazards to people from nuclear-space power sources resolve into a potential contribution to the world's background level of radioactivity and the chance of radiation hazards to local populations during either launching or re-entry operation. We will start by explaining why the first of these is not too difficult a problem and then go on to examine the question of local hazards.

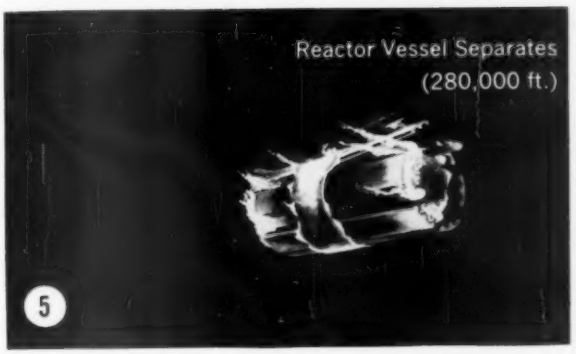
World-wide Radiation Levels

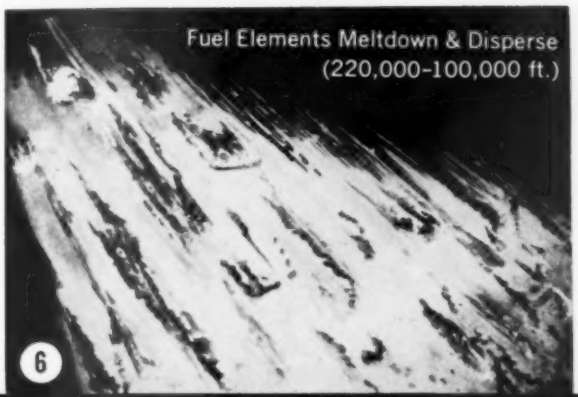
The total radioactivity that could credibly be released over the next 20 years from the combined operations of nuclear flight systems—including nuclear manned aircraft, and the nuclear ramjet as well as the nuclear rocket and the space auxiliary power devices—if distributed on a global scale could cause only a minor change in the existing levels due to natural sources.

The surface of the earth has an area of about 5×10^8 km^2. This much radioactivity deposited uniformly over the earth's surface would have a surface concentration of about 2×10^{-3} curies/km^2. The total mass of the atmosphere is 5.2×10^{21} grams. One megacurie is more than the source strength of a 125 watt SNAP 1A and much more than the radioactivity expected for a SNAP reactor core upon re-entry to the atmosphere. One megacurie of radioactivity mixed uniformly into the entire mass of the atmosphere would (taking into account the density change with altitude) have a sea level concentration of approximately 2×10^{-13} curies/m^3, or 0.5 disintegrations per minute in a cubic meter (compared with normal background of $\sim$100 dist/min-m^3).









The AEC's Division of Biology and Medicine is now engaged in a study to take into account any addition of C^{14} to the environment from direct neutron radiation from space reactor power sources. Again, this is expected to be quite small.

To minimize the problem still further, vehicles that contain nuclear sources would, as a matter of policy, normally be used in orbits whose life times are long enough to allow nearly complete decay of all radioactivity before re-entry. For instance, if a SNAP-2 reactor unit operated in orbit at 50 kw(th) for one year, its core would contain 2×10^5 curies of fission product activity (which would include 85 curies of Sr^{90} and 64 curies of Cs^{137}). But we can conveniently select an orbit for this mission that would allow over 100 years of cooling before the SNAP core eventually returns to burn up in the atmosphere (reducing the radioactivity to a few curies). With these cooling times, even if we launch SNAP-2 units at the presently estimated maximum rate of 10 units per year, the contribution of radioactivity to the atmosphere would be undetectable.

A second precaution that would normally be observed whenever the mission allows would be to delay starting up nuclear reactor systems until the vehicle has attained an acceptable orbit.

Perhaps the most convincing demonstration of the relative insignificance of radioactivity inventories involved in these systems came about in efforts to plan experiments to investigate the dispersion in the atmosphere of the radioactivity following burnup on re-entry. Investigation found that the amount of radioactive material contained in an isotopic device (SNAP-3 type) is much too *small* to serve as a radioactive *tracer* material for these experiments.

We are convinced that the potential increases in worldwide background levels which might arise from the development of all of the aerospace nuclear power sources (as forecast for the next twenty years) will be small compared with present natural levels. This assumes successful development and subsequent full operational use (during the second decade) of all major aerospace nuclear programs now underway. This conclusion about total radioactivity would remain valid even with a parallel effort elsewhere matching that of the United States.

Local Hazards

There are four periods in the operational life of a nuclear space device (see Fig. 1) during which hazards to local

FIG. 2. COMPLETE BURNUP ON RE-ENTRY is achieved for SNAP reactor through special design features that promote quick separation of reactor components; meltdown and effective dispersal of radioactive fuel occurs above altitude of 100,000 ft

population areas could conceivably develop.

—During takeoff at the launch pad

—During ascent under positive control by the flight-range safety officer

—During post-flight-range ascent into orbit or to escape velocity

—During re-entry following successful orbit or escape.

Safety features already built into our missile range operations are adequate to protect local populations against any radiation hazards during the first two of these four phases of flight. The third phase poses the bulk of the problems at this time; there are questions raised by the last phase but they are comparatively easy to solve. We will see that the problem of guaranteeing safety for either of the two last phases can be reduced to one of guaranteeing that the nuclear component will burn up completely as it re-enters the earth's atmosphere.

Launch-Pad Safety

Launch-pad safety involves safeguarding people and property against radioactive contamination of the environment, conventional fire and explosion. During launching either a fuel tank rupture or guidance system failure would require command destruct of the vehicle. Two severe environmental conditions can result—explosion and fire. The forces of fuel explosion in typical operational missiles create blast overpressures of the order of 10,000 psi. Launch pad fires reach temperatures of the order of 6,000° F for microsecond periods but rapidly decrease to temperatures between 1,600° and 3,000° F with burning times up to 30 minutes.

For the isotope SNAP devices, designers have encapsulated the radioactive heat source in materials, such as molybdenum and Inconel, that are rugged enough to withstand this kind of treatment. Tests in which SNAP 1-A and SNAP-3 cores were subjected to simulated launch pad aborts have conclusively demonstrated the containment of the radioactive material.

SNAP reactor devices, since they would not be started before an acceptable orbit is attained, would contain no reactivity on the launch pad. The only possible hazard at this time would be the remote chance of an accidental criticality which might then lead to partial destruction and release of fission products formed during the excursion.

For the SNAP-2 unit under the worst conditions (a strong inversion, one hour full power operation on the pad followed by a 50 Mw-sec excursion and release of all fission products) the radiation exposure directly downwind at the center of the fission product cloud is estimated to be less than 60 mr at a 12 mile radius. The annual tolerable exposure limit for the general population is 170 millirem per year.* This radius could touch small portions of the population near to controlled areas.

Since the SNAP reactors are specifically designed to prevent accidental criticalities such an excursion is quite unlikely; even were one to take place the potential hazard is small.

The situation is similar for the Kiwi-type propulsion reactors. According to our present thinking, on space missions they would not be started on the launch pad. However there is the small risk of accidental criticality; also the AEC is now carrying out on-the-ground static tests in Nevada.

The vast Nevada Test Site is entirely adequate to contain this hazard, as would be expected with certain precautions for the Pacific and Atlantic test range sites when the time comes for flight tests.

Controlled Flight Phase

After launch, the vehicle travels for a fairly long distance under positive instrumented control—i.e., the range safety officer can destroy the vehicle at any time it appears to deviate from an acceptable trajectory. The flight would take place over the long stretches of open ocean available on either a polar orbit trajectory at our Pacific missile range or a southeast trajectory (below the tip of Africa) at our Atlantic missile range. For instance, at the Cape Canaveral missile range positive control extends for over 4,000 miles across the Atlantic past Ascension island. A vehicle failure during this period would result in a nuclear power source falling intact (or for a reactor device, perhaps, in large chunks) into the sea, with some small probability of striking uninhabited islands. Maximum expected velocities would be of the order of 500 ft/sec.

For a sea impact nuclear components would be heavy enough to sink immediately to the bottom and the materials involved are highly insoluble. For the isotope devices, sea-water corrosion studies on SNAP 1-A and SNAP-3 fuel capsules show conclusively that the capsules will not release any radioactivity until the activity level is well below one curie. SNAP 1-A and SNAP-3 cores have also successfully survived impact tests on granite at over 500 ft/sec on Aberdeen Proving Grounds supersonic ballistic sled track.

For reactor systems, aside from the hazard of falling hardware (which would be no greater than for our present tests during this stage of flight), the only possible problem would be criticality on immersion in water or impact on a hard surface. Designers are providing core geometries that will rule out this possibility.

The destruct devices now in use during this phase of vehicle flight operate with high reliability (less than one failure in 10,000). This reliability, coupled with past experience in making accurate impact prediction and maintaining long-range communications, assures positive control of the vehicle during this phase.

Random Re-entry

After the vehicle has gone beyond the region of positive control it can still fail to attain the velocity vector needed to go into its correct orbit and will then be subject to "random re-entry." However it will, at this point, be above the atmosphere so that if it returns to earth from a poor orbit or does not orbit at all it will burn up as it re-enters the atmosphere. The problem is to guarantee that it will burn up completely, for any re-entry trajectory that would lead to an impact outside the ocean test-range-area. The critical parameters are the velocity and angle of re-entry—a piece of hardware of given materials, con-

* The Federal Radiation Guides suggest 170 mr/yr (for the general population) maximum permissible exposure (on a genetic basis) and 500 mr/yr for individuals within the general population (on a personal risk basis). Higher exposures are allowed by these Guides in situations of national interest (e.g., the 500 mr dose being $\frac{1}{10}$ the exposure allowed to workers in the nuclear field). In any event, the intent is to work within the limits suggested by the Federal Radiation Council Guides.

figuration and dimensions will burn up on re-entry at a given angle for all velocities above a certain value.

For instance SNAP isotope and reactor devices have been designed so that they will burn up on re-entry at speeds above 24,000 ft/sec given a burn-up time of at least 300 sec. A vehicle that reaches this speed in a preorbital failure will also have a very shallow angle of re-entry (less than 0.1 degree to the tangent). These conditions would yield temperatures above 4,000° F for over 300 sec and a peak temperature in excess of 5,500° F for over 15 sec. Enough heat would be generated to ensure complete burnup of SNAP units above 100,000 feet.

However our experimental information is not yet good enough to determine the minimum burnout velocity for these units to the accuracy needed to be certain that no failures will impact beyond the test range. If this velocity is indeed 24,000 ft/sec then there is no problem (see Fig. 3) since all failures at lower velocity would come down at distances less than 10,000 miles from the launch point—comfortably within the 12,000–15,000 mile expanses available at either our Atlantic or Pacific missile ranges. But if this velocity were to turn out to be 25,000 ft/sec there is a small but finite probability (of the order of 1 in a 1,000) that vehicle hardware can land beyond the missile range in foreign countries.

Even so any radioactive hazard from vehicles carrying nuclear power sources would be confined to a narrow velocity band (100–200 ft/sec), just below the minimum burn-up velocity, in which burnup would be partial. Below this band the vehicle would land intact. We know that the isotope devices can withstand such impacts. If neither the SNAP or Rover reactors are started until orbit is attained there would be no radioactivity to release so that the main hazard from their systems would be the falling hardware.

If we wanted to use a Rover reactor for a first-stage booster or second-stage sustainer unit it would have to operate before reaching orbit. As a booster, impact would always be within the established missile range. However, a second-stage rocket could theoretically land anywhere along its trajectory if it failed to orbit. Within the narrow velocity band of partial burnup its radioactive core would come down in pieces or, at lower velocities, land intact.

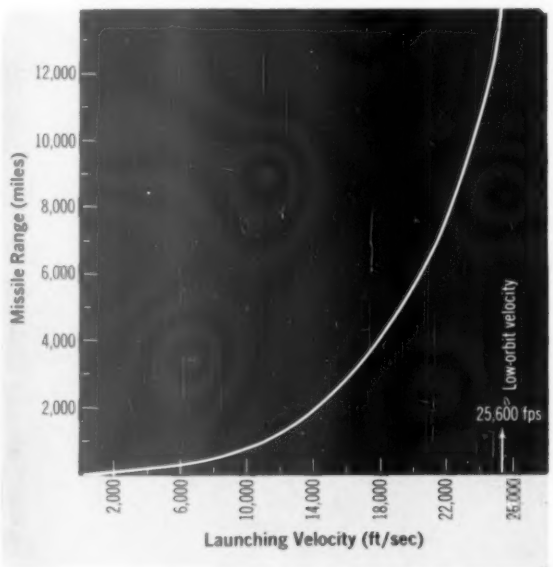


FIG. 3. DISTANCE OF IMPACT from launch point vs. burnout velocity. Vehicle needs at least 25,600 ft/sec to orbit

Our program aim is to rule out the possibility of either partial burnup or intact landings outside the established flight range by assuring complete burnup. For both SNAP and Rover systems this means designing into the systems special engineering features to promote easier burnup. Extensive flight tests will provide the basic data needed for these designs and verify their performance reliability.

Random re-entry is also the result of the fourth flight phase—the eventual descent of the vehicle from a successful orbit.

The problems here are easier than for the third phase because:

- Re-entry velocities would always be higher than in the third phase
- Long-lived orbits (20–100 years) would be chosen to allow the radioactivity of nuclear sources to decay to low values before descent (see table) (vehicles which go into shorter-lived orbits than planned would be counted as "phase-3" failures, their reactors would never be started up).

If we solve the problem of guaranteeing burnup for phase 3 then we also have it solved for this last phase.

Burnup Dispersion

A final question might be raised about burnup as a solution. Granted complete burnup, do we know that the dispersion of the radioactive products from a reactor core or isotope device will be great enough to avoid localized radiation exposure? Although we have no direct experience at such high altitudes, we can make estimates of the distribution and transport of the burnup products from lower altitude information now available from weapon-test debris, industrial pollution and meteorological experience. These estimates (which take into account latitude, season of the year and some other factors important in interpreting weapons data) indicate that the concentration of products from a burnup could be a factor of four up to, at worst, a factor of ten greater than the concentration for world-wide uniform distribution. We have seen that world-wide levels for the total release expected from the whole nuclear space program will be very minor; a factor of ten increase in concentration for a single release will then still not be a major problem.

Designing for Burnup

The object is to design space nuclear power sources to burn up at re-entry velocities low enough to guarantee that no hardware (whether radioactive or not) will ever land outside the test ranges. However, these same devices must resist burnup in a launch-pad failure or, for reactor cores, operate normally at the highest possible design temperatures. The designer can make an effort to find materials with melting points low enough to burn on re-entry but high enough to stand up under the other requirements. He can also devise ways to make the ratio of surface area to weight presented by the components in

Extraterrestrial Contamination

Scientists interested in studying the origin of matter would like to guard against the contamination of the natural radioactivity of other bodies in the solar system by activity transported from earth. This possibility exists if controls and retro mechanisms fail. To get around this problem for the isotope SNAP unit that might power the first soft-lunar-landing vehicle, designers would take the precaution of using isotopes that are fairly certain not to occur in nature or that have a short half-life. Cm^{242} and Pu^{238} are artificially produced alpha-emitting isotopes that have never been found in meteorites or in spectroscopic observations within the solar system; they have the added advantage of emitting very few gammas and hence would not interfere with gamma surveys of the natural activity.

falling through the atmosphere as large as possible.

For instance the SNAP isotope devices might profitably consider trading their present molybdenum or inconel fuel capsules for ones made of lower melting alloys. This would buy a lower burnup velocity at the expense of some launch-pad reliability. (Now that we have developed and completely tested devices that automatically eject SNAP units clear of the vehicle in the event of a launching failure, the SNAPs appear over-designed for launch-pad reliability.) We would be making a good bargain if we reduced the odds against a radioactivity release at launching from 1 in a million to 1 in 10,000 in exchange for a decrease in burnup velocity from 24,000 ft/sec to 18,000–20,000 ft/sec. Burnup could then be guaranteed for any missile that got beyond 4,000–5,000 miles downrange. (In reducing the launch pad reliability we are not increasing the chances of public hazard since we have already seen that the present range exclusion areas are adequate to handle any radioactive release. The gamble is really an economic one—we would be taking a 1 in 10,000 chance of paying, say, up to $100,000 to decontaminate the test area.)

The problem of burnup design for reactor devices is even more difficult because the components involved are more massive than for the isotope sources and reactor cores contain materials (such as Be, graphite, UO_2 and stainless steel) especially selected for their high temperature endurance.

In the SNAP reactors, to expose the fuel elements to aerodynamic heating as quickly as possible, the structural materials surrounding the reactor would be held together by fusible links that will melt at about 2,500° F and allow the reactor components to fall apart on re-entry to the atmosphere (Figure 3). To make for easier burnup, the Be reflector, for example, might be formed of small cubes of Be held together in a jacket made of a lower melting point material such as nickel.

Rover type reactors present the biggest burnup problem of all. With the present materials and designs, these reactors would require some positive means of destruction to assure burnup. Concepts that have been considered include an intentional excursion of the reactor core, disintegration with explosives, and thermal shock and oxidation from flushing liquid oxygen or fluorine through the hot reactor. Another method of disposal might be to propel the core into deep space at the conclusion of the mission with propellant held in reserve for this purpose.

Flight Testing

We will need extensive flight testing first to establish the empirical data needed to design for complete burnup and other safety features and, second, to proof test the finished designs.

On the question of re-entry heat transfer and burnup, for instance, we now use mathematical models that draw on known handbook properties bolstered by ground tests with plasma jets and nose-cone re-entry data. Flight tests will give us a chance to verify the mathematical models for a spectrum of shapes, sizes and materials. As an illustration of how refined these calculations become, local variations in the force of gravity with position along the vehicle flight path can add up to a final impact difference of as much as 600 miles.

Weapons' tests have provided information about the particle size and distribution of radioactive material, but we will want to check these factors for the non-explosive situation and also at the higher altitudes involved in re-entry.

At the point of proof testing, tests of dummy prototypes will precede tests of the actual devices. Before we send up a live SNAP-3 for burnup tests we will send up a SNAP-3 unit with the radioactive isotope replaced by an inert material.

The Rover system tests, will, of course, require elaborate flight tests to demonstrate the reliability of techniques and equipment for reactor control (including orbital startup and shutdown), positive destruction and controlled re-entry or escape. To a large extent, these studies will merge with programmed flight tests to develop the Rover rocket systems themselves.

A Rover rocket could be flight tested in the SATURN system from Cape Canaveral in two different ways: first, as an upper stage in a high altitude lob shot; and then, as an upper stage with orbital start-up (assuming adequate destruct control) on a southeast trajectory. These assumptions are based on existing missile trajectory and nose cone re-entry data.

Orbit Lifetime as a Function of Orbit Height*

Orbit altitude (Naut. miles)	96	131	161	232	328	365	450	500	2,000
Orbit lifetime	1 day	1 wk	1 mo	1 yr	10 yrs	20 yrs	100 yrs	300 yrs	1,000 yrs

* These are approximate values. Precise values will vary with drag weight ratio.

* * *

The authors wish to thank the members of the Aerospace Nuclear Safety Board; the staff of the Aircraft Nuclear Propulsion Office and the AEC-NASA Nuclear Propulsion Office of the Division of Reactor Development of the Atomic Energy Commission—in particular the SNAP and Rover project officers; and the members of the SNAP Safety Committee for their cooperation and aid in the preparation and review of this paper.

Electric Power Sources

SECTION II—*The useful career of a space satellite is fixed by the life of its auxiliary power supply. In the 1–100 watt range, radionuclide SNAP units (see below) provide hard-to-damage, continuous sources of electric power with completely predictable lifetimes. The first space job given these devices promises to be that of supplying 19 watts to NASA's soft lunar landing mission. SNAP reactor units (p. 73) appear to be the only practical means of supplying the tens-of-kilowatt needs of the future. Both direct-conversion and turboelectric versions should be ready well before 1970*

Radionuclide Power for Space Missions

AUTHORS

Douglas G. Harvey *is Project Engineer in charge of the Space Systems project of the Auxiliary Power Systems Dept in the Martin Company's Nuclear Div. He is responsible for design, development and test of all Martin radioisotope power systems. From 1953 to 1956 he served as officer in charge of Radiation Effects Studies at Wright Air Develop. Center.*

Jerome G. Morse *is Manager of Auxiliary Power Systems Dept. of Martin Company's Nuclear Div. Morse came to Martin in 1955 from the faculty of the U. of Miami in 1952 where he was Dir. of the Radioisotope Lab. Previous to this Morse received his doctorate in physical chemistry from Illinois Institute of Technology and worked as a research chemist with GE.*

To MEET THE NEED of space missions for new, environment-independent sources of energy, the AEC is sponsoring the SNAP program (systems for nuclear auxiliary power). Even-numbered SNAPs (discussed in the article that starts on Page 73) get their energy from fission reactors; the odd-numbered SNAPs, which we will discuss here, convert the heat developed in radioactive decay into electrical energy.

Investigations in recent years show that radionuclide power will be particularly suited to the following types of missions:

- equatorial-orbit missions lasting more than a year in which the discharge cycle exceeds energy-storage capabilities of other sources
- lunar missions in which lunar night exceeds battery storage capability
- probes into the dense atmosphere of Venus
- space probes proceeding away from the sun.

Heat Source

There is no lack of nuclides with characteristics (thermal power density, half-life, type of activity, etc.) that make them appropriate for radiation-powered generators (*1*). Thermal requirements are shown by Fig. 1 (*4*), and characteristics of several heat sources are listed in Tables 1 and 2. But although many suitable nuclides exist, availability is another problem. There is a lack of facilities to separate the ones that are fission products; thus fission-product availability is contingent on need. In general, fission products such as Sr^{90} are cheaper than reactor-produced nuclides such as Po^{210}.

Both beta- and alpha-emitting nuclides offer satisfactory power densities for periods of usefulness that are proportional to their half-lives. Shielding requirements for beta sources depend mainly on the bremsstrahlung radiation they produce. Shielding of alpha sources is considerably simpler, but some shielding is required by reactions that produce neutrons in such low-Z materials as boron, nitrogen, fluorine, etc.

Containment of radioactivity under all conceivable conditions of aborted mission, corrosion, external and internal pressures and burnup on re-entry adds to the

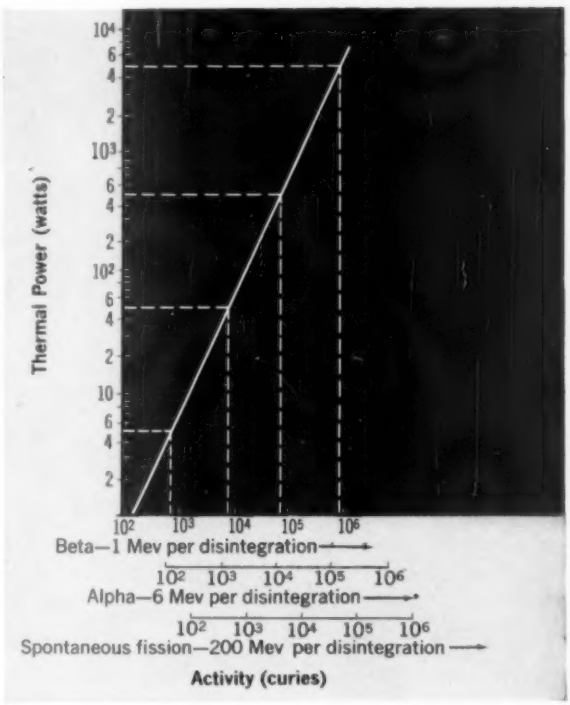


FIG. 1. THERMAL OUTPUTS FROM NUCLIDE SOURCES as functions of activity and types of emissions (*4*)

problem of encapsulation, but the problem has been solved in ways that would be satisfactory for a number of missions planned for the future (see p. 64). Such strong, high-temperature materials as Inconel X, Hastelloy B and René 41 are suitable for thermoelectric devices operating with hot junction temperatures of 1,000°–1,700° F. Refractory metals such as molybdenum, tungsten, tantalum, and rhenium are under consideration for nuclide containment in thermionic devices for which cathode temperatures may be as high as 3,700° F. Alpha emitters require containment of helium at high pressures that depend on fuel quantity, pressure, void volume and time. A similar problem exists for other nuclides that change their valence state as they decay so that gas is released from a chemical compound. For example:

$$20\ CeO_2 \xrightarrow{\beta} 10\ Pr_2O_3 + 5\ O_2 \xrightarrow{\beta} 10\ Nd_2O_3$$

TABLE 1—Typical Radionuclide Heat Sources

Nuclide	Mode of decay	Half-life	Fuel form	Density (gm/cm³)	Thermal power (watts/cm³)	Fuel required (curies/watt)	Estimated costs ($/watt) Current	Projected
Po^{210}	Alpha	138 d	Po	9.3	1320	31.2		
Cm^{242}	Alpha	162 d	Cm_2O_3	11.75	1169	27.2	80*	45*
Pu^{238}	Alpha	86.4 yr	PuC	12.5	6.9	30.3		1600
Ce^{144}	Beta	285 d	CeO_2	6.4	12.5	128	87	14†
Pm^{147}	Beta	2.6 yr	Pm_2O_3	6.6	1.1	2700	3000	1630†
Cs^{137}	Beta	33 yr	CsCl	3.9	1.27	320	500	54†
Sr^{90}	Beta	28 yr	$SrTiO_3$	4.8	0.54	153	455	23†

* Irradiation cost not included (rate of increase = $100/watt).
† AEC estimates based on construction of major separation facility.

Energy Conversion

For efficient and reliable SNAPs only thermoelectric and thermionic conversion are useful for powers less than a few hundred watts. Early missions will use thermoelectric converters, but for future missions we are extensively studying thermionic systems with such significant advantages as higher heat-rejection temperatures, smaller weights and greater efficiencies.

Lead telluride is considered to be the only truly operational thermoelectric material available today. Among other promising thermoelectrics that are currently being developed are cadmium sulfide, cobalt silicide and gadolinium selenide. They offer Seebeck coefficients comparable to that of lead telluride but high-temperature performance as well.

These materials would eliminate the present requirement of dumping excess heat and thus permit much greater power output at the start. If constant power were required, excess power could be dumped electrically to make possible a far lighter and more efficient system than present ones.

Engineering Design

In making an operational power source from the basic science that is available as a starting point, a designer has three principal problems to solve: (a) power flattening, including the dumping of excess heat, (b) achieving structural integrity and (c) matching the electrical load.

If one is to have constant power output from an exponentially decaying heat source, excess thermal power must be dumped during initial phases of operation, either as heat or as electricity. When conversion is thermoelectric, the thermoelectric material dictates the method of dumping. With lead telluride, for example, sublimation at high temperatures limits hot-junction temperature to 1,000° F. On the other hand, power output falls off rapidly below 900° F. Keeping the hot junction between these limits requires dumping excess energy as heat.

One of the most important aspects of detail design is structural integrity. Two problems must be considered: ability of the generator to withstand severe acceleration, vibration and shock at launching and integrity of the fuel core in an aborted mission.

A d-c-to-d-c converter generally matches the output of the generator to the requirements of the load. Such a converter is a completely static, solid-state device with a flip-flop circuit, transformer, rectifiers and filter. Converter efficiencies as great as 85% have been achieved, and 70% is relatively easy at the potentials in question (3–30 volts).

Systems Now Under Development

Principal characteristics of four odd-numbered SNAPs that are intended for space missions are listed in Table 2. The first of these is hat-sized SNAP-3 (*2*). At present it is undergoing tests for integrity and reliability based on actual environment in a Thor-Able rocket.

SNAP-3 generators have been tested by vibration twice in each of three perpendicular planes. Some reduction of

FIG. 2. SOFT LUNAR LANDING GENERATOR is intended for moon mission in which landing shock is limited to 100 g

power output has been observed, and some noise appears on an oscilloscope, but power always returns to its original value within 5 min of cessation of the test. SNAP-3s have also been subjected to accelerations as great as 15 g for 5 min in each plane of symmetry with no effect. They have suffered 50-g shocks with rise times <1 msec in three perpendicular directions. All generators operated satisfactorily after these tests.

SNAP-9—14.5 Watts for 5–10 Years

Since one of the principal purposes in the design of SNAP-9 is long life, it is fueled by a long-lived nuclide and has a relatively low hot-junction temperature to provide long life for its thermoelectric elements.

Solar cells are unsuitable for this mission because of problems of energy storage and Van Allen radiation. Sohn has pointed out that Van Allen radiation causes significant reduction in solar-cell output when the integrated dose exceeds 5×10^{13} electrons/cm² (*3*). Since during the 5-year minimum lifetime of a SNAP-9 the system will be subjected to $\sim 10^{15}$ electrons/cm², one cannot use solar cells except with very heavy filters. Such filters become opaque to ultraviolet light and decrease the electrical output they are intended to sustain.

The selection of long-lived Pu^{238} as fuel removes the problem of power flattening, but it leaves two other problems: fuel containment and radiation. For containment, a fuel that is solid at operating temperature is preferable, but plutonium metal melts at 1,170° F. The carbide, by comparison, melts at a temperature greater than 3,600° F and fulfills the requirement of a solid fuel form.

Radiation from metallic plutonium consists of neutrons from spontaneous fission and photons from gamma decays.

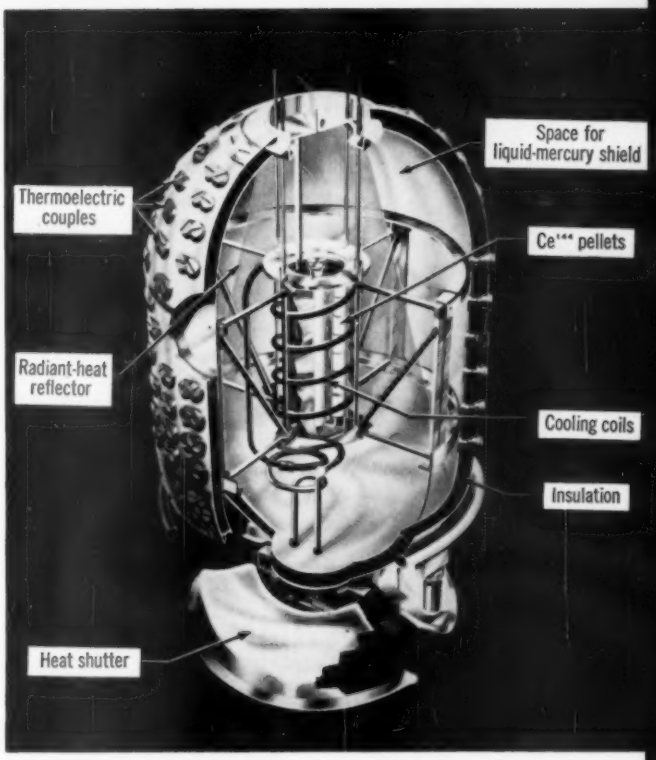


FIG. 3. HIGH-POWERED SNAP-1A has thermoelectric elements between two outer shells, drainable 4,000-lb mercury shield

TABLE 2—Four Radiation-Powered Generators

	SNAP 3	SNAP 9	SLLG*	SNAP 1A
Design power out (watts)	~3	14.5	19	125
Weight (lb)	4	11.9	16.6	200
Design life		5–10 yr	4 mo†	1 yr
Maximum input power (watts) (at time of loading)	70	260	655	6,500
Fuel nuclide	Po^{210}	Pu^{238}	Cm^{242}	Ce^{144}
half-life	138 d	86 y	163 d	285 d
amount	2,300 c	475 gm‡	6.3 gm	8.8×10^5 c
Maximum hot-junction temperature (°F)	1,050	900	1,000	1,050
Maximum cold-junction temperature (°F)	300	235	370	335
Length (in.)	5.5	7	8.38	34
Diameter (in.)	4.75	12.5	7.5	24

* SLLG = Soft Lunar Landing Generator.

† Life includes three months of useful operation plus one month between fueling and beginning of use.

‡ Weight of plutonium carbide.

But when the carbide is used, an additional reaction becomes significant: α,n in the carbon. The dose rates from these α,n neutrons in the vicinity of the generator are roughly 20 times what dose rates would be from the same amount of Pu^{238} as a metal. For example, one expects 0.957 rem/hr from metallic fuel, 20.5 rem/hr from α,n neutrons both measured at 1 yard from the center of the generator.

Most of these neutrons come from C^{11}; in C^{12} neutron binding energy exceeds the alpha-particle energy, and the reaction does not occur. If pure C^{12} were used, one would have dose rates similar to those from metallic plutonium.

Electrical output will be a usable 12 watts at 18 volts. This comes from a d-c–to–d-c converter which is 83% efficient, and the input to the converter is from 36 pairs of ½-in. thermoelectric elements, which generate 3 volts under load at 6.54% efficiency.

Six aluminum fins dissipate heat and provide a surface temperature of 215° F, 20° below the cold-junction temperature because of a drop across the cold caps.

Soft-Lunar-Landing Generator

Designed for a moon mission in which the landing shock will be limited to 100 g, the Soft Lunar Landing Generator (SLLG) is shown in Fig. 2. It would have as fuel a gold-curium alloy (5 parts of gold to 1 of curium by weight). Fueling will occur as long as 30 days before launching, and

after launching, the device is to operate three months or more on the mission. For power flattening excess heat would be dumped from the heat source at a rate that is selected by an automatic shutter.

The gold-curium alloy was selected both because it is easily fabricated and because the gold reduces the specific power to an acceptable value. The fuel design is a hollow cylinder with the fuel alloy in a tantalum liner (for chemical protection) and this, in turn in Hastelloy C (for strength).

The internal void of the capsule is a reservoir for accumulation of helium produced in alpha decay of the fuel; small holes in the inner surface of the liner would permit the gas to flow to the void.

The tantalum liner is required to prevent corrosive attack by plutonium, which is produced in the decay of curium. Tantalum is essentially inert to plutonium at the temperatures of the heat source. If there were any unpredicted deterioration of the fuel alloy, the liner would also contain the products.

Since during the 240 days in which the generator is supposed to operate helium would reach a pressure of 7,870 psi—ten times what tantalum would stand by itself—the outer container of Hastelloy C is added for strength. Hastelloy C is corrosion and temperature resistant and readily burnable under re-entry conditions.

The thermoelectric portion of the generator consists of 30 pairs of lead-telluride elements putting out an over-all potential of 3.0 volts. Efficiencies are: thermoelectric, 6.51%; thermal, 73.5%; over-all, 4.0%. *p*-type elements are doped with 1.0% of sodium, and *n*-type with 0.03% lead iodide. Design inputs are 752 watts at encapsulation, 655 watts at launching, 475 watts at the end of life.

The heat dump has a fixed radiator attached to the heat source at the end containing the fuel capsule. Covering the radiator is an insulated shutter, which is moved by thermal expansion of molten NaK in a loop near the hot junction. The shutter is fully open to permit maximal radiation to space at the start of the mission and fully closed at the end.

Shielding required for safe ground handling is 1.6 in. of water, which reduces radiation intensity to the prescribed 60 mrem/hr at 1 meter. Without the shield, the dose rate from all radiations would be 125 mrem/hr at 1 meter.

SNAP-1A—125 Watts for Space Missions

The radiation-powered generator for greatest output is SNAP-1A, designed to weigh 200 lb as it flies away. A mercury shield of more than 4,000 lb can be drained just before launching. SNAP-1A will supply 4.46 amps at 28 volts to an external load of 6.28 ohms.

As is indicated in Fig. 3 the unit is a cylinder with hemispherical ends. The shell, which contains the thermoelectric elements, is made up of two hermetically sealed skins separated by insulating material (Min-K-1301). A stainless-steel inner skin is the hot junction, and an aluminum outer skin is the cold junction.

The fuel capsule is an Inconel X cylinder, 11 in. long and 3¾ in. in diameter. Ceric-oxide fuel pellets go into seven thin-walled stainless-steel tubes, and these in turn into the fuel capsule.

As shown in Fig. 3, the capsule is supported at the center of the unit by tubular truss members and load members that pass through top and sides to attach to the flight vehicle.

During ground handling mercury fills the interior to provide shielding. A water coolant coil around the fuel capsule takes heat from the mercury. Just before launching the mercury is drained, and heat from the fuel is permitted to pass to the inner of the two insulated shells by radiation.

Testing. We are now testing SNAP-1A under a program designed to show its reliability and safety. Successfully completed tests apply to the following: (a) fuel form and fuel container development, (b) launching-pad failure of flight vehicle, (c) ascent failure of vehicle and (d) simulated orbital re-entry with a plasma-jet generator.

Shock, vibration and acceleration tests are currently under way on a second prototype generator.

A third generator is under construction; it will be used for nuclide fueling.

What Will SNAPs Cost ?

The SNAP-3 system is now ready for actual space use, with SNAP-1A soon to be operational. SNAP-3 has been successfully ground-operated for more than a year. Advancement in the technology of direct conversion will lead to higher temperatures, greater efficiency, smaller fuel inventories, lighter systems. Thermionic technology, which is also developing at a rapid rate, offers the additional advantage of higher heat rejection temperatures. Within a dollar framework these growth factors are reflected as shown in the table. The fuel cost is considerably greater than the cost of the remainder of the power system.

Basic to the use of nuclear energy in space is the technical assurance that established safety criteria are met. A considerable portion of the AEC SNAP program has been devoted to comprehensive analyses and tests, the results of which prove that such criteria can be satisfied by nuclide power systems.

Nuclide power systems provide a reliable answer to space power requirements in the range of one to several hundred watts in which the unique characteristics of long-lived constant power output are paramount. Such systems eliminate the need for energy storage and are independent of altitude and orbit.

Cost of 100-Watt Ce^{144} Power Supply (1-year life)

Conversion system	Thermal output (watts)	Quantity of fuel (10^3 curies)	Fuel production cost ($10^3)
Thermoelectric (5% efficiency—available today)	5,000	675	70
Thermionic (13% efficiency—available in 1965)	2,000	270	28

BIBLIOGRAPHY

1. J. G. Morse, "Nuclear Flight," p. 138 (Duell, Sloan and Pearce: New York, 1960)
2. G. M. Anderson, M. Barmat, E. W. Bollmeier. SNAP III—electricity from radionuclides and thermoelectric conversion, NUCLEONICS **17**, 5 (1959)
3. R. L. Sohn, "Review of Solar Cell Power Systems," paper presented at AIChE Symposium on Unconventional Sources of Electrical Energy (New York, October, 1960)
4. S. H. Clark. Radioisotopes as sources of heat, *Atompraxis*, January, 1960

FIG. 1. LOW-POWER (0.1–10 kw) SNAP thermal reactors such as SNAP-10A will use thermoelectric converters to power devices aboard surveillance satellites (left). MEDIUM-POWER (1–100 kw) SNAP-2 and SNAP-8 turboelectric systems will be used in satellites (center) for worldwide TV and radio. HIGH-POWER (0.1–10 Mw) systems using fast reactors and advanced turboelectric or thermionic converters would electrically propel rockets (right) for exploration of planets of the solar system

Compact Reactors for Space Power

AUTHORS

H. M. Dieckamp *is the Chief of Space Power Section of the Compact Power Systems Dept. of Atomics International. He was project engineer for the design and construction of the SNAP Experimental Reactor. Since joining the SNAP program, he has been responsible for the design of test facilities and the planning of the tests for SNAP 2.*

Ralph Balent *is Director of the Compact Power Systems Dept. of Atomics International. He is responsible for the SNAP reactor projects AI is conducting for AEC. Balent joined NAA in 1950 and became Group Leader of Preliminary Analysis in 1954. He has been Group Leader of General Engineering and Deputy Director, Organic Reactors Dept.*

J. R. Wetch *is Deputy Director of the Compact Power Systems Dept. at Atomics International. Prior to his present position, Wetch was chief project engineer for the SNAP project and headed the development of SNAP 2 since its inception at AI. Before he joined NAA in 1952 he helped design the "K" production reactors with the General Electric Co. at Hanford.*

ONLY A FEW WATTS of electrical power for a matter of days or weeks were required for a space vehicle during the first three years of the era of space exploration (Explorer, Vanguard, Pioneer). Extensions of space exploration (Ranger, Surveyer, Prospector), along with military programs (Midas, Samos, Advent), will require hundreds of watts of auxiliary power for periods of a few months to a year. These programs will be followed by Tiros and Transit for worldwide TV and communications, which will require auxiliary power units in the killowatt range. Finally, planetary exploration (Mariner, Voyager) along with electrical propulsion by about 1965 and manned space flight by about 1970 will require units producing hundreds of kilowatts to tens of megawatts.

Recognition of the high specific-energy potential ($\sim 10^6$ watt-hr/lb), orientation independence, compactness, ruggedness and adaptability of reactor power units has led to the SNAP reactor power systems program shown in Fig. 1 and the table (*1, 2*).

SNAP Criteria

The considerations governing design choices for SNAP-type reactors include:

- **Low weight.** Since it costs $1,000–15,000 to put each pound into an earth orbit, a high premium is placed on lightweight systems.
- **High temperature.** Since heat generated in space vehicles can be dissipated only by radiation to space, the system must operate as hot as the "state-of-the-art" will permit so as to minimize radiator area and weight.
- **Reasonable cost.** Cost must not be so high that it limits application in operational systems.
- **Growth potential and adaptability.** The system must be compatible with advanced missions and improved power-conversion technology.
- **Schedule.** Extension beyond existing technology must be limited so as to minimize development time.
- **Long life with exceptional reliability.** Because of the cost and complexity of putting payloads into space, power sources must have reliably long life. The SNAP approach to reliability is simplicity—moving parts, valves, control loops, filters and auxiliary systems are either eliminated or minimized.

The silent vacuum environment of outer space almost excludes external effects, except for the possibilities of meteorite damage or diffusion welding of hot surfaces in

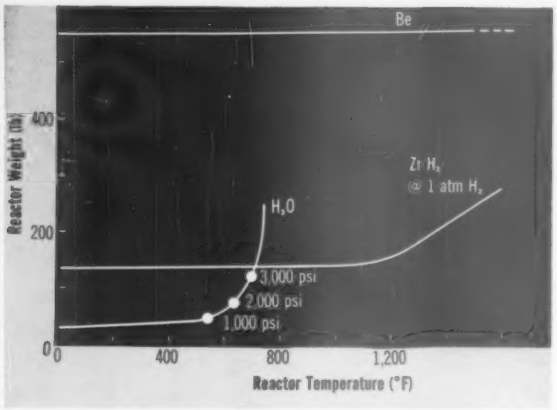


FIG. 2. HOW OPERATING TEMPERATURE of various moderator materials affects reactor weight for systems having 5 kg U^{235} critical mass (as bare spheres). ZrH_x moderator gives lightest-weight epithermal reactor above 600–700° F

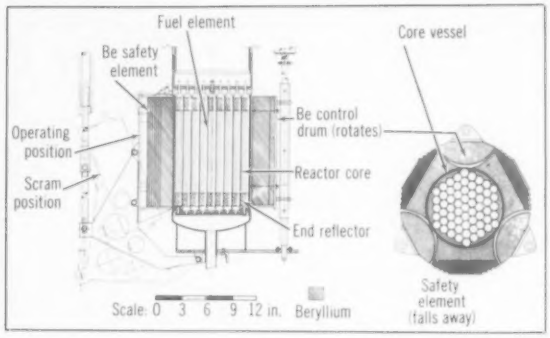


FIG. 4. SNAP EXPERIMENTAL REACTOR (SER), which demonstrated SNAP-2 reactor thermal and nuclear operation, has 61 solid-hydride rod fuel-moderator elements 10 in. long with additional 1.5-in.-long Be slug and ½-in. plug at each end (total length = 14 in.) of type 347ss cladding tube. Fuel rods are on 1.015-in. centers in triangular pattern making up hexagonal core 8 in. across flats and 9 in. across corners. Be shims fill void between core and 9-in.-i.d. core vessel. Reactor heat is removed by 11 gpm Na78K to secondary NaK system, thence to air. SER operated for SNAP-2 equivalent of ½ full-power year

contact and the increased friction of sliding surfaces (see p. 93). These problems are surmountable by proper material selection and design. Micrometeorites do not present a significant problem to the reactor because of its size and configuration. For example, a core vessel with 1 ft² of vulnerable area must be only 50 mils thick for a 90% probability of no punctures in 1 yr and 100 mils thick for a 99% probability. But the launch environment imposes unique requirements—all parts must withstand about 10g of vibration and 100g of shock.

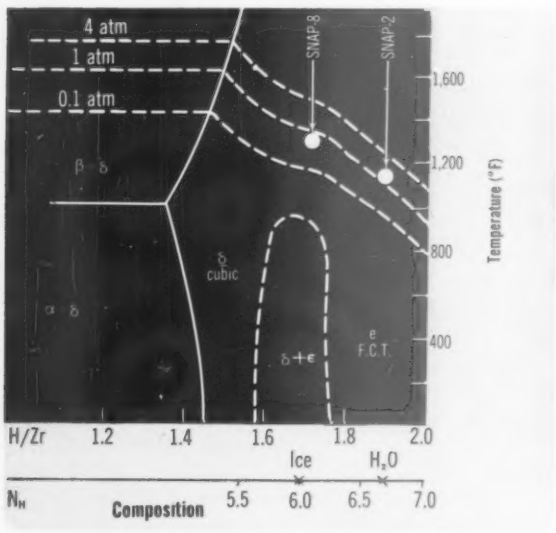


FIG. 3. Zr-H PHASE DIAGRAM shows that epsilon-phase ZrH with hydrogen density equivalent to that of cold water (N_H = 6.7) can be used at 1,200° F with a dissociation pressure ~1 atm. Density does not change when cubic delta phase changes to face-centered-tetragonal epsilon phase and no anomalies are apparent in the two-phase region. Because U in ZrH_x exists in separate dispersed phase islands, it does not change thermodynamics of hydride

Current SNAP Designs

Fast reactors, because of their high cost (a critical mass would cost about $1-million) and less-proven technology, were ruled out in favor of thermal or epithermal reactors for systems generating less than 100 kw(e). The size of these types depends mainly on the moderator material. The table shows the characteristics of the various SNAP-type reactors.

Moderator. The common moderators, in order of increasing reactor size, are H_2O, Be, BeO, D_2O and C. Figure 2 shows how reactor weight increases with temperature of H_2O, Be and ZrH_x moderators. Water moderation gives the lightest room-temperature reactor, but above 600–700° F the pressure needed to suppress boiling makes the pressure vessel too heavy. Beryllium can be used up to about 1,500° F, but the reactor weighs 550 lb. Carbon and D_2O are even more unsuitable.

Transition metal hydrides can provide hydrogen density comparable to that of cold water (6.7×10^{22} H atoms/cm³), and thus permit a reactor the same size as the water-moderated reactor—at elevated temperatures but without high pressure. Zirconium hydride is stable to about 1,200° F; beyond this point the hydrogen dissociation can be limited by a cladding material (only 1% H is lost per year from SNAP-2).

Fuel material. Figure 3 shows the current zirconium-hydrogen phase diagram. During irradiation of capsules of fueled zirconium hydride in MTR at about five times the 3.1×10^{11} SNAP-2 average flux, in-pile instrumentation indicated no change in thermal conductivity and no radiation augmentation of the thermal-dissociation pressure. After samples achieved the SNAP-2 average burnup of 0.026 metal at%, post-irradiation metallurgical examination revealed no density change or loss of physical integrity.

The SNAP reactors use fully-enriched uranium in a homogeneous mixture with the moderator so as to minimize weight. This homogeneous arrangement means that the entire core is producing power and absorbing fission-

product damage. Thus, for a given volume, a homogeneous reactor has lower surface heat-transfer fluxes and produces more total energy at the same atom-percent burnup than the same-size heterogeneous core.

Beryllium is used as the reflector because it is light, can withstand the high operating temperature and has high neutron reflectivity. Optimum reflector thickness is about 2 in. Because of the small reactor size, almost 40% of all neutrons born in fission leak from SNAP reactors. Thus changes in reflector effectiveness strongly influence neutron economy—so total control can be achieved by varying reflector thickness, as shown in Fig. 4 (*3*).

Liquid metals are the only coolants compatible with the light-weight and high-temperature requirements of space reactors.

Power Conversion

Nuclear heat can be converted to electrical power either by thermoelectric or turboelectric devices. With either conversion method, and contrary to earthbound power stations, waste heat from a space power unit can be discarded only by thermal radiation to space.

Thermoelectric systems. For low-power space systems (0.1–1 kw), the weight of the power-conversion unit is not a major item, so the choice can be based on reliability and simplicity. Even though thermoelectric power-conversion systems have over-all efficiencies of only a few percent, they are attractive since they have no moving parts and thus should have reliably long life. It also is simple to start them remotely after the space vehicle has attained the desired orbit. Although consideration has been given to a SNAP design (SNAP-10) in which heat is conducted from the reactor through an annular array of thermoelectric converters and then to radiating fins attached to the cold junction, above a few hundred watts the conversion efficiencies and temperatures needed exceed the present $<1{,}000°$ F capability of the lead-telluride class of thermoelectric materials. This power limitation can be circumvented by using a pumped NaK loop to transfer reactor heat to the thermoelectric converter—this allows the large radiator surface with less weight than with a conduction system. Figure 5 shows such a system, SNAP-10A.

Turboelectric systems. For medium power (1–100 kw), the weight of the power-conversion system becomes a major part of total system weight. Since the radiator is a large part of this weight, the radiator area per unit heat-rejection rate is a principal parameter in selecting the

SNAP Reactor System Parameters‡

Parameter	*SER*	*SNAP-2‡*	*SNAP-8*
Output, kwe	0	3	35–70
Thermal kw	50	50	600
Efficiency, %	—	6	11.5
Converter	None	Hg Rankine	Hg Rankine
Available, yr	1959	1964	1965
Minimum life, yr	—	1	1
Reactor size, in.	17 × 15 dia	16 × 14 dia	19 × 15 dia
Core volume, ft³	0.35	0.3	0.48
Power density,*			
Mw(th)/ft³	0.143	0.165	1.25
Reactor wt,† lb	300	250	400
System wt,† lb	—	750	1,400
Specific wt,† lb/kwe	—	250	40
Fuel-moderator			
rods, number	61	37	211
Dia. × length, in.	0.975 × 10	1.21 × 10	0.53 × 14
U in ZrH_x, wt%	6.88(x = 1.7)	9.85(x = 1.85)	9.85(x = 1.7)
U^{235}, kg	3.0	4.3	7.0
N_H, H atoms/cm³	6×10^{22}	6.5×10^{22}	6.0×10^{22}
Max. temp., °F	1,300	1,300	1,450
Cladding	347ss	Hastelloy-N	Hastelloy-N
Wall, mils	10	14	10
O.D., in.	1	1.25	0.56
Heat flux,*			
Btu/hr/ft²	12,400	17,000	55,000
Neutron flux, n/cm²/sec	4.4×10^{11}	3.1×10^{11}	2.3×10^{12}
Reflector			
Axial, in.	1.5 Be	1.5 BeO	None
Radial, in.	3 Be	2.3 Be	3 Be
Be control drums	3	2	2
Be safety plates	3	2	2
Reactor coolant	Na78K	Na78K	Na78K
Temp. out, °F	1,200	1,200	1,300
Temp. in, °F	1,000	1,000	1,100
Hg boiling, °F	—	900	1,070
Hg condensing, °F	—	600	700
Radiator area, ft²	—	110	400–800
Radiator,* °F	—	600	700
Contractors:			
Reactor	Atomics International	Atomics International	Atomics International
Converter	None	Thompson Ramo Wooldridge	Aerojet

* Average. † Unshielded. ‡ In the 0.5-kw(e) SNAP-10A system, 900° F Na78K from a 25-kw(th) SNAP-2 reactor heats the hot junction of separate lead-telluride-class thermoelectric converters to 850° F. Cold junction is at 590° F and radiator temperature is 580° F with 140 ft²/kw area. Unshielded, the system weighs 325 lb for the reactor and structure plus 500 lb/kw for the converter-radiator. SNAP-10A is to be available by 1963. Its lifetime should be 1–3 yr.

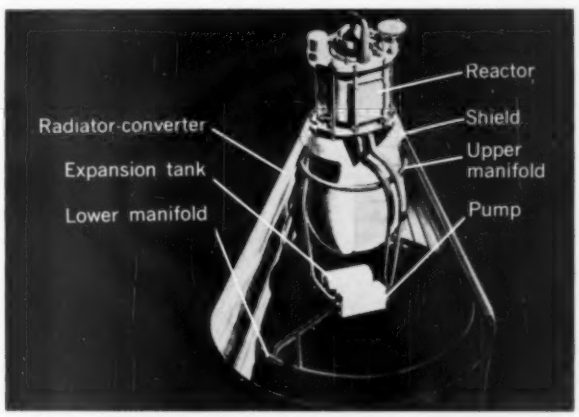


FIG. 5. THERMOELECTRIC CONVERTERS in SNAP-10A system are coupled to a SNAP-2 reactor via an electromagnetically pumped NaK loop. System will generate up to 1 kw(e). Shadow shield decreases neutron scatter by components, keeps shield weight low. After startup in orbit, negative temperature coefficient of reactivity controls reactor without further control-system motion

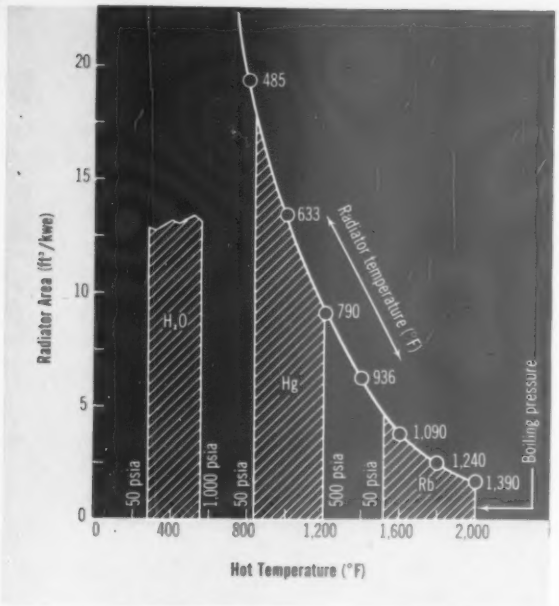


FIG. 6. WITH 1,000–1,400° F OUTLET temperatures of SNAP-type thermal-reactor systems, mercury is working fluid that best fits Rankine-cycle requirements. Curve assumes: (a) practical cycle efficiency is 40% of theoretical Carnot; (b) smallest radiator area occurs when cycle cold temperature is at ~75% of hot temperature. For given hot temperature, Brayton-cycle gas-cooled reactors are less efficient, require bigger radiator

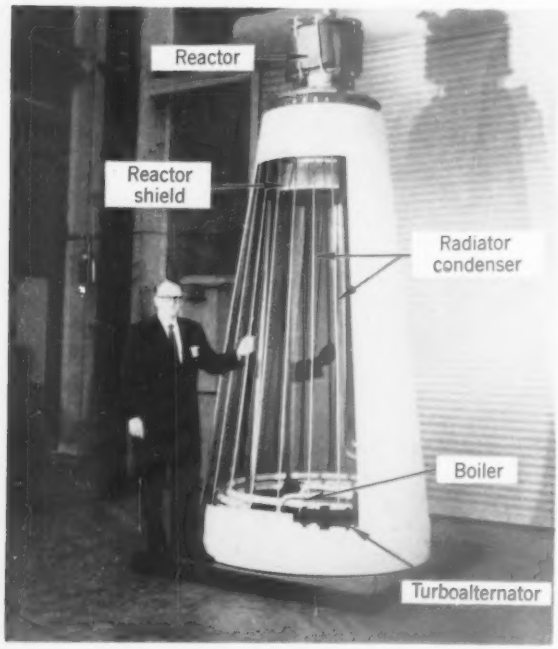


FIG. 7. SNAP-2 FLIGHT CONFIGURATION, as shown by full-scale model, would have reactor at one end beyond conical shadow shield (reactor weighs 250 lb when 13 ft separates payload and reactor), boiler and turboalternator-pump unit at other end, and combined radiator-condenser (small parallel tubes attached to high-conductivity metal skin) that radiates condensation heat to space is between. Typical tolerances for transistorized payloads: 10^{12} nvt fast neutrons, 10^7 r gammas

power-conversion system. Figure 6 shows practical operating ranges for various working fluids in the Rankine-cycle. Both SNAP-2 (Fig. 7) and SNAP-8 use the mercury Rankine system.

In addition to the radiation heat sink, the space environment imposes design problems of maintenance-free long-time operation and zero-gravity conditions. For reliability, all the power-conversion rotating components are mounted on a single common shaft assembly called the combined rotating unit (*4*). Five or six combined rotating units have been tested at rated conditions for a total of more than 1,300 hr (one has operated 580 hr so far).

Advanced Systems

Unless the radiator runs hotter, when higher-power units are built increased radiator area makes the system more susceptible to micrometeorite puncture. For a specified reliability then, more micrometeorite shielding is needed around the radiator tubes of higher power reactors such as SNAP-8. To hold low specific weight at higher power levels, radiator temperatures must be increased. Megawatt power levels with specific weights less than 10 lb/kw can be achieved with radiators at 1,200–1,500° F. In concept, these temperatures can be reached in systems with ceramic-fueled fast reactors that either are coupled to high-temperature alkali-metal Rankine vapor turbine-generator systems or incorporate thermionic converters in the core.

For the advanced Rankine system, rubidium or potassium appear suitable as working fluids. The fluid either can be boiled in an external boiler-superheater (as with SNAP-8), or this heat exchanger can be eliminated and the fluid boiled directly in the reactor. For in-core thermionic conversion, the fuel elements themselves would serve as the cathode elements. Each fuel element (cathode) would be separated from the anode by a small (few mils) cesium-vapor-filled gap. The anodes would be insulated electrically from the cladding, which in turn would be cooled by an alkali liquid metal that would be pumped directly to the radiator for heat dissipation. Power densities of 10–20 electrical watts per cm^2 can be achieved with cathodes at 3,000–3,300° F (*5*) and 950–1,300° F anodes.

Both the advanced Rankine and thermionic reactor systems require intense high-temperature material and fuel research that would be followed by component development and system testing (*6*). Research and study programs are being sponsored by the USAEC, Air Force and NASA.

BIBLIOGRAPHY

1. R. Balent. Nuclear reactor heat source for Project Feedback. NAA-AER-896 (1954)
2. R. C. Brumfield, R. Balent. Auxiliary power plant prime mover and electrical generator for Project Feedback. NAA-AER-897 (1954)
3. SNAP-2 reactor makes debut. NUCLEONICS **18,** No. 1, 104 (1960)
4. D. L. Southam. SNAP-2 power conversion status. American Rocket Society paper 1326-60 (Space Power Systems Conference, September 30, 1960)
5. N. S. Rasor. Parametric optimization of the emission-limited thermionic converter, American Rocket Society paper 1283-60 (Space Power Systems Conference, September 30, 1960)
6. NUCLEONICS **19,** No. 2, 82 (1961)
7. G. M. Anderson, J. Wetch, H. Dieckamp. The practical application of space nuclear power in the 1960's (paper presented to the XI Astronautical Congress, Stockholm, Sweden, August 15, 1960)
8. G. M. Anderson. SNAP-2—a reactor-powered turboelectric generator for space vehicles, paper 154B (SAE National Aeronautical Meeting, New York, 1960)
9. G. M. Anderson. The SNAP program—present status and future prospects (paper presented at Atomic Industrial Forum, December, 1960)

Nuclear Rockets

SECTION III—*With three successful full-power tests to encourage them (see below), Rover personnel are preparing KIWI-B tests—to start this year and to be the first ground test of a flight configuration. At the same time work continues independently on the two major problems of a high-thrust nuclear rocket engine—high temperature fuel materials for the reactor core (p. 85) and engine control during quick startup (p. 80). Graphite, refractory metals and ceramics look best for service > 2,000° C. Dynamic analyses define two control systems satisfying startup needs*

Kiwi Tests Pave Way to Rover

THREE ROVER REACTORS have been designed, fabricated and tested by Los Alamos Scientific Laboratory. These test operations and the research and development that made them possible demonstrate that high hydrogen temperatures can be produced by heat-exchanger reactors whose startup, stable operation and shutdown pose no unexpected problems. Intensive laboratory studies on materials, heat transfer, thermal stress, neutronics and controls and measurements helped provide fairly predictable components for the reactors, although not all the reactor conditions could be simulated in the laboratory nor all interactions anticipated.

The three reactors tested to date are Kiwi-A (July 1959), Kiwi-A′ (July 1960) and Kiwi-A3 (October 1960). Each test has involved only a single full-power run so as to provide a well-defined operational history on which to base conclusions from detailed post-run examination of components. This is particularly true for radiochemical analyses, which are used to determine the fission distribution and fuel temperature distribution by the differential migration of fission products.

Kiwi-A

The Kiwi-A reactor used uranium-loaded graphite-plate fuel elements in an annular zone around an ~15-in.-dia central island containing circulating D_2O and control rods. Outside the fuel zone was a flow-separator cylinder, an outer reflector (both of graphite) and a water-cooled double-wall pressure vessel made of aluminum. For test runs, the reactor was mounted on a special railroad car with the exit nozzle pointed upward (Fig. 1). Made by Rocketdyne, the double-wall exhaust nozzle also was water cooled.

The reactor. The fuel plates, each 8 in. long, ¼ in. thick and 5–8 in. wide, were stacked in graphite cylindrical boxes or "whims" in such a way that the longitudinal ribs on one surface of each fuel plate kept a 0.050-in.-thick passage for gas flow. LASL fabricated the fuel plates by methods that incorporated the U^{235} (as uranium dioxide) early in the process. Each plate was loaded uniformly, but the loadings of the various plates differed according to heat-transfer and fission-distribution calculations and data for its axial or radial position. A graphite disk pierced by

AUTHOR

Raemer E. Schreiber *is the Leader of N-Division at Los Alamos Scientific Laboratory. His division was established in 1955 to work on Project Rover. After he joined LASL in 1943 Schreiber helped build the first water-boiler reactor and was a member of the nuclear assembly team for the nuclear bomb operations at Alamogordo, Tinian, Bikini and Eniwetok*

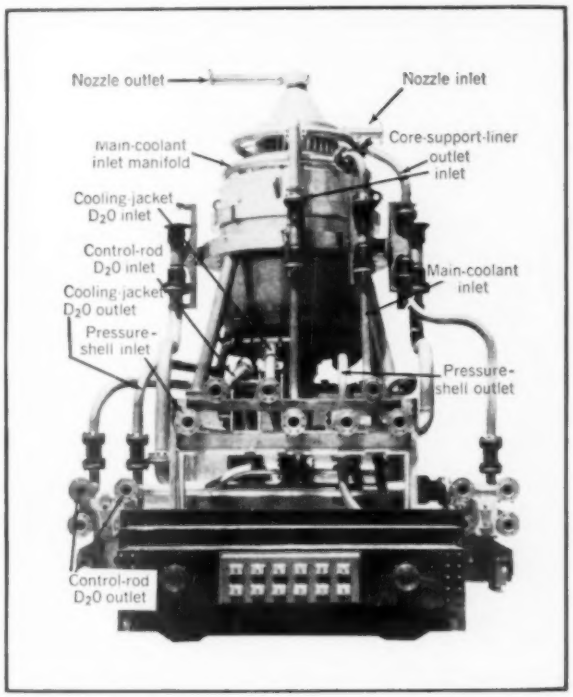


FIG. 1. KIWI-A REACTOR on its test car (as seen from test-cell face). Concrete umbilical plug on nose of cart carries control and instrumentation leads and mates with corresponding opening in test cell. Coolant and propellant lines are attached to test cell by quick-disconnect fittings

FIG. 2. Kiwi-A, like other Kiwi reactors was assembled on stand before being mounted on test car. Propellant inlet section is shown at right. Wires dangling from bottom of pressure shell connect with instruments inside reactor. Actuators and sensors for linear control rods will be suspended from bottom center of reactor later

FIG. 3. KIWI TESTS (Kiwi-A3 at full power shown at right) used intermittent firings of chemical rocket (left) to mark hydrogen cloud so aircraft could sample it. Dose rates were less than tolerance at all distances beyond point where reactor radiation predominated; beyond 2 miles radioactivity was insignificant. Maximum contamination was $\frac{1}{2}$–1 mile downwind

coolant passages served as neutron reflector on the inlet side of the reactor core.

Pressurized hydrogen gas entered the reactor via a plenum at the upper end of the reflector, flowed through holes in the reflector down into the core inlet plenum, then flowed up between the fuel plates, into the core exhaust plenum and out the nozzle. The central island contained the regulating, shim and scram rods, which were moved by external double-acting hydraulic pistons through sliding seals at one end of the island.

Assembly, checkout. After initial non-nuclear assembly at the Albuquerque division of American Car and Foundry Industries (which was responsible to LASL for detailed mechanical design, fabrication of nonnuclear hardware, field assembly and disassembly), Kiwi-A was moved to Los Alamos and checked at low power. Then it was shipped to AEC's Nevada Test Site, where it was assembled (Fig. 2) and mounted on its test car and then moved by rail to the test cell and installed (Figs. 1 and 3). The reactor control system and numerous data channels were tested, calibrated and perfected during the spring of 1959.

Operation. On July 1, 1959 the operators brought Kiwi-A to low power, purged the propellant lines and reactor with nitrogen and started hydrogen flow. To prevent hydrogen from accumulating and causing an explosion hazard, a methane torch near the reactor nozzle ignited the hydrogen as it flowed from the reactor. The operators increased hydrogen flow and reactor power and, after two pauses to observe equilibrium conditions, took the reactor to its rated power and temperature for several minutes as planned. After power was decreased to an intermediate level, a sine-wave generator oscillated a special control rod at various frequencies so data could be obtained on reactor response to reactivity variations. Then the operators inserted the control rods to shut the reactor down and adjusted gas flow to remove afterheat.

Instrumentation. Neutron level, and thus power level, was measured in ion chambers on and near the test cell. These had been calibrated by radiochemical analyses of fission foils that had been put in the reactor and activated at lower powers. Further calibration data were gathered when a small fast reactor ("Little Eva") was operated at the test cell before Kiwi-A was installed.

Several linear and logarithimic channels reported reactor power to the control room that was located about two miles from the test cell. These channels fed into a computer that in turn adjusted the control rods so as to hold a power level specified by the operator (he also could move the rods directly). Period and power-level scram circuits guarded against excursions.

A venturi and flow computer measured hydrogen flow; the operator could control the throttling valve directly or could set it to hold a specific flow automatically. From the measured flow rate and pressure at the nozzle inlet, an analog circuit computed hydrogen exit temperature and displayed it at the operator's console. Transmission, calibration and recording of data was the responsibility of the firm of Edgerton, Germeshausen and Grier.

Thermocouples, pressure taps and position transducers were located throughout the reactor. As expected, some thermocouples burned out during the full-power run, but their readings during startup and lower temperature operation gave valuable data.

Post-operation examination. Several days after the power run, the reactor was moved to the shield dis-

assembly building where remote manipulators were used to take it apart. All parts were inspected visually and by other means for evidence of damage or change. Since Kiwi-A used unprotected graphitic fuel elements, it was known that corrosion by the hot hydrogen would limit its performance. The operating temperature was chosen to produce measurable corrosion and permit comparison of reactor results with laboratory experiments. Detailed post-mortem examination of the fuel plates (including weighing, dimensional checks, chemical and radiochemical assays, radiography and autoradiography) showed no disagreement with laboratory results.

Kiwi-A′ and Kiwi-A3

Several weeks before Kiwi-A tests were completed, design work started on Kiwi-A′, which used a new core geometry. External features of the reactor were deliberately made identical with Kiwi-A to simplify tests; it reused some of the Kiwi-A test-car hardware.

After the usual preliminary checkouts and low-power runs, Kiwi-A′ was brought to full power on July 8, 1960 and run through a power-flow profile similar to that of Kiwi-A. A programmer was used during the climb to power to slave the gas flow to the demanded power so as to achieve a nearly constant rate of temperature change in the fuel elements. After the full-power run, power was dropped step-wise twice to determine transient response.

Although Kiwi-A′ performed successfully, there were enough discrepancies between its actual and predicted behavior to cause some design changes for Kiwi-A3, which was put through its power run on October 19, 1960.

Facilities and hardware improvements. New methods introduced during the 1960 reactor tests include:

- Use of programmed reactor startup.
- Quick disconnect fittings for gas and liquid lines simplified hookup and speeded the disassembly of the "hot" reactor after test operation.
- Multiplexing, magnetic-tape recording and digital data reduction were used on some of the data channels of Kiwi-A3, replacing the direct recording and point-by-point data reduction used on Kiwi-A.
- During the Kiwi-A3 run, several measurements were made using a stochastic technique to determine response characteristics of the reactor control system; small random power commands were fed in by a punched tape and the reactor power output was cross-correlated with these commands to yield data on the impulse response of the power control system.

Kiwi-B Plans

The Kiwi-B test series will start in 1961 as soon as test cells are ready and reactor design and fabrication are complete. In mid-1960 work started on a new test cell for using pumped liquid hydrogen as the reactor coolant. The original test cell also is being enlarged and equipped for handling liquid hydrogen.

The use of liquid hydrogen as reactor coolant offers a number of new problems. For instance, while calculations and analog simulation studies of the effect of high hydrogen densities in the core are reassuring, the first reactor startup with liquid hydrogen should be an interesting experiment. Further, Kiwi-B tests are intended to establish the design

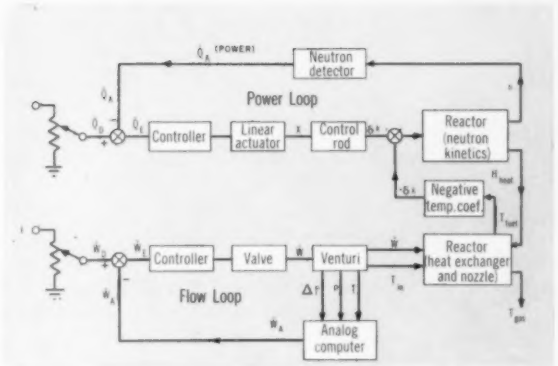


FIG. 4. IN KIWI-A POWER CONTROL LOOP, power Q_D is demanded by setting voltage on potentiometer, which compares command signal with actual signal Q_A from neutron detectors. Resultant error signal Q_E commands motion of control rods through controller and linear actuator. Temperature coefficient of reactor constitutes internal loop that combines with change in reactivity produced by control-rod motion. Flow command W_D similarly is generated by a potentiometer setting. Flow is sensed from absolute pressure, pressure drop and temperature measurements in venturi in propellant gas supply. Analog computer converts measured values into "actual flow" voltage W_A that is compared with demand and difference or error W_E drives throttling valve through controller

of a propulsion reactor suitable for use in a flight-test engine.

Nozzles and liquid-hydrogen feed systems for Rover uses are being developed by the Rocketdyne division of North American Aviation for NASA. Bendix research division and the General Electric aircraft accessory turbine department are developing radiation-resistant control actuators for AEC, while Oak Ridge National Laboratory is assisting LASL fabricate fuel elements for the Kiwi-B reactors.

To prepare to test actual nuclear engine systems, the Aetron division of Aerojet General is designing an upward-firing test stand for "breadboard" or prototype engine testing. This work is being coordinated with other AEC-NASA facility planning.

* * *

In addition to the organizations already mentioned as having major responsibilities for Rover work, the firm of Burns and McDonnell was architect-engineer for the original NTS test complex; Air Products, Inc., is architect-engineer for the current work on the cryogenic test stands, and Reynolds Electric Co. has a continuing responsibility for the maintenance and minor construction work at the Nevada Test Site. The Sandia Corporation furnished valuable technical assistance for the Kiwi-A tests. Space does not permit a complete listing of the individuals and many organizations that are contributing to specialized areas in the Rover development work.

BIBLIOGRAPHY

1. J. Grey. Nuclear rockets. NUCLEONICS **16,** No. 7, 62 (1958)
2. A closer look at the real Kiwi-A, NUCLEONICS **18,** No. 4, 96 (1960)
3. F. P. Durham. Solid core nuclear rocket design, *J. Am. Rocket Soc.* **4,** 10 (1959)
4. "Nuclear Flight," Lt. Col. K. F. Gantz, ed. (Duell, Sloan and Pearce, 1960)
5. R. E. Schreiber, Frontiers in atomic energy research, p. 275 (JCAE Hearings, March 22–25, 1960)
6. How they tested the first nuclear rocket engine, *Control Eng.* **6,** No. 11, 130 (1960)
7. B. J. Brettler, Instrumentation system for the Kiwi-A reactor, paper presented at Sixth Annual Meeting on Nuclear Science of the IRE (Boston, Mass., November 19–20, 1959)

Nuclear Rocket Engine Control

A NUCLEAR HEAT-EXCHANGER rocket engine requires a fairly sophisticated control system. Start-up has to be rapid (in less than a minute) to minimize rocket attitude control problems and to conserve propellant. The desired thrust must develop over the proper time interval. If the reactor is to be reused, the shut-down program must account for the decay of neutron and gamma ray heating. At all times exhaust gas temperature should be kept high to maximize specific impulse.

These requirements dictate an automatic control system, with carefully designed programming of several interrelated variables. Our studies at Los Alamos show that control by a system of this kind is feasible. However, much additional study, supplemented by live testing of engine control systems, will be needed to create an actual control system for a reactor flight test.

The studies to date show that the reactivity of hydrogen in the core is a stabilizing influence provided the hydrogen is not inadvertently present in liquid form. Ultimately it may be possible to develop a very simple control system based on the coupling of reactor power with propellant flow through the reactivity of hydrogen in the reactor core.

In this article we will review the demands made on a nuclear-rocket engine control system, describe two possible systems, and discuss preliminary results for the dynamic behavior of these two systems.

AUTHORS

Ronald R. Mohler *has been working as a staff member at Los Alamos on the analysis of nuclear-rocket-engine control systems since 1958. Previously he worked on automatic flight control systems with Hughes Aircraft. While at Los Alamos he has taught graduate courses in reactor control theory at the Univ. of New Mexico*

Joseph E. Perry, Jr. *is Group Leader at Los Alamos in charge of developing reactor controls for Rover. Perry worked at Berkeley and Oak Ridge on electromagnetic separation during 1942–45. Before he came to LASL in 1950 he took his Ph.D. in physics from the Univ. of Rochester and conducted research at Cal Tech*

Basic Engine Systems

The engine we will consider is shown schematically in Fig. 1. Rotating cylindrical control drums located in the reflector control the reactor power. A turbopump draws liquid hydrogen from the thin-walled storage tank and circulates it at a high pressure, in sequence, through the nozzle cooling jacket, the reflector, the reactor core and the nozzle throat. The liquid turns into a gas in the nozzle jacket or the reflector. In the "bleed cycle" (Fig. 1) hot gas from the reactor core or nozzle mixes with liquid from the pump to create gas of proper temperature and pressure to drive the turbine. Gas from the turbine is available for attitude control jets.

Operational Requirements

The basic demand made of a rocket engine is that it impart a given velocity increment to the rocket with minimum consumption of propellant. In a chemical rocket this is achieved by abruptly starting the engine at the proper time and spacial orientation, and abruptly stopping it after a predetermined interval of time. Several factors make engine operation more difficult for a nuclear rocket (*2*).

- During start-up the reactor will have to traverse the last three decades of power in less than a minute (possibly a few seconds!)—an operation completely unthinkable in the traditional high-power reactor business.
- The coupling of reactor power with turbopump speed in the bleed cycle must be adjusted so that the engine can "bootstrap" itself along a constant specific speed line to achieve full operation in the desired time.
- Sufficiently fast start-up can lead to intolerable thermal

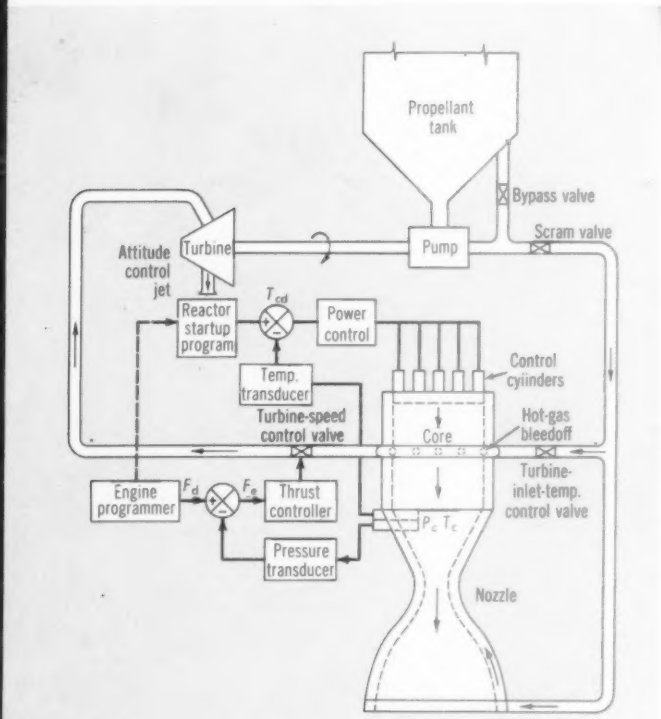


FIG. 1. ENGINE-SYSTEM SCHEMATIC for nuclear rocket shows hydrogen flow path from storage tank to exhaust nozzle. Also shown are control systems for turbopump, thrust and temperature

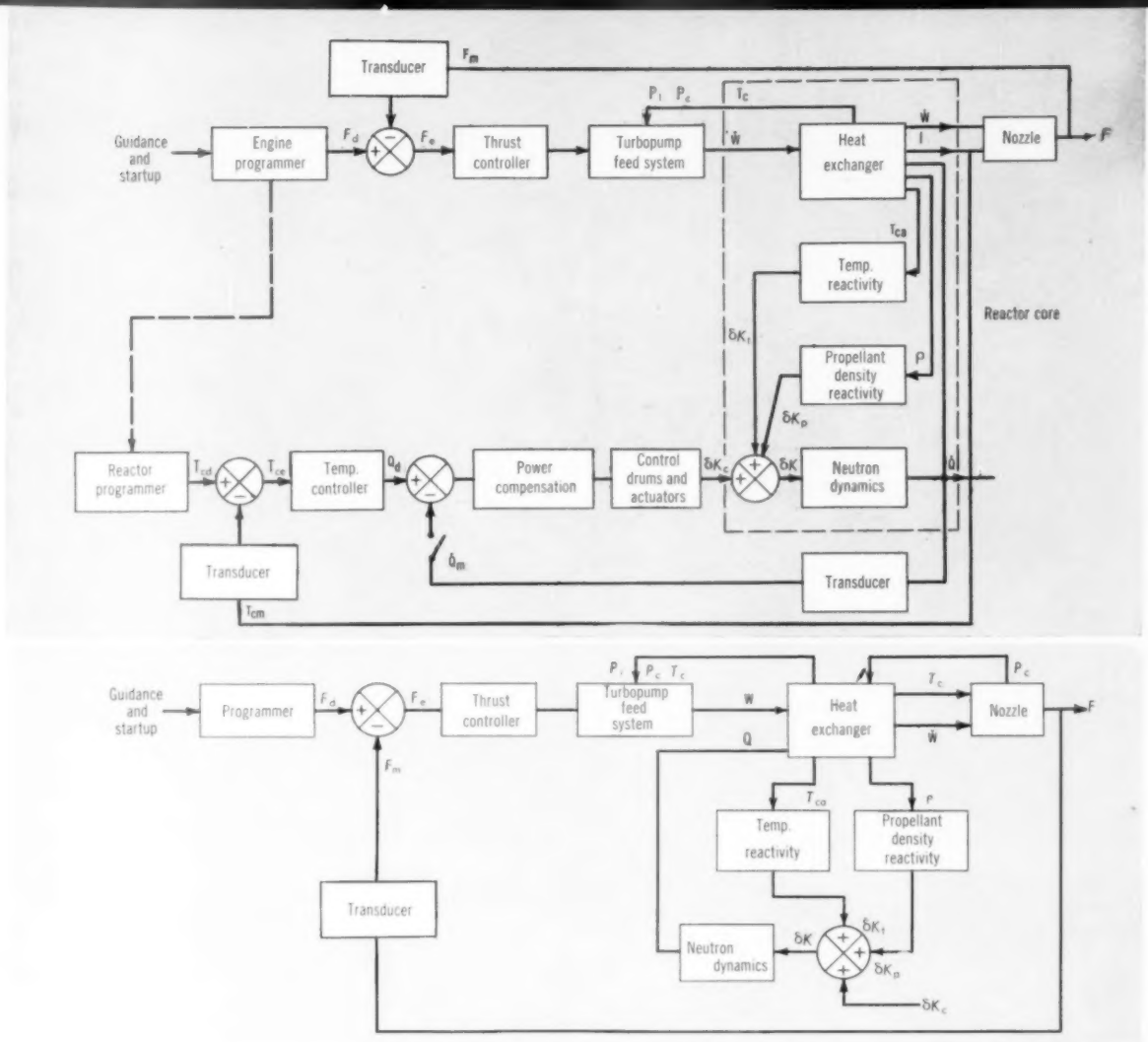


FIG. 2. CONTROL SYSTEM BLOCK DIAGRAM (a) for conventional engine-control system in which engine thrust and reactor temperature commands derive from basic vehicle velocity loop (not shown) and (b) advanced system in which reactor power and propellant flow are coupled through reactivity of hydrogen density in reactor core, allowing for much simpler system

stresses or pressure drops in the heat exchanger, and possibly to excessive reactivity if liquid H enters the core.

Fundamentally engine performance is limited by the power density in the reactor, the pressure and temperature which the core can contain, the flow available from a lightweight turbopump,* and the weight increase as the nozzle expansion ratio is increased. With these variables specified the engine can be designed for maximum specific impulse and maximum thrust (4).

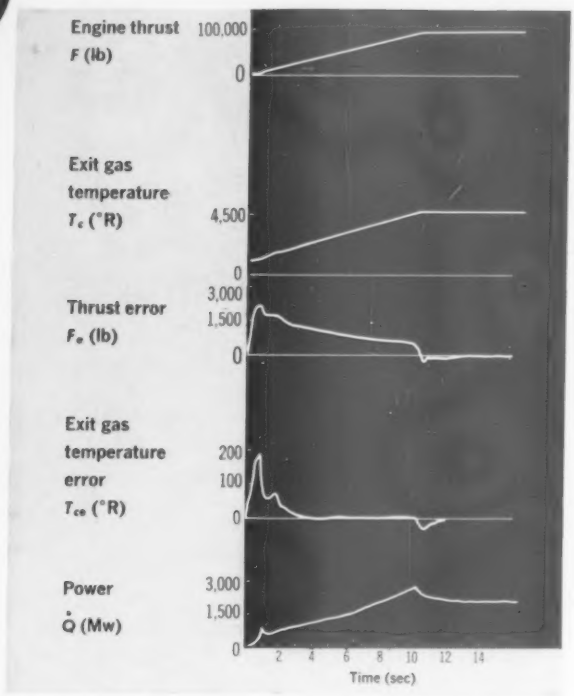
Choosing Control Variables

The basic control variable on the nuclear rocket stage will undoubtedly be velocity—the time integral of the output of an accelerometer yields the desired velocity increment. Beyond this no definitive statement can be made at the moment. Clearly several subservient variables will be controlled, some will be programmed, and some may be slaved to others. The interaction of the many pertinent variables is under intensive study. The ultimate optimum choice will depend on the results of these studies, on the availability of fast-response sensing devices to measure the variables in the radiation-vibration-temperature environment of the engine, and on experimental tests of various control subsystems at the Nevada Test Site.

We will describe two of the most promising control systems we have studied. In the first system, (Fig. 1 and Fig. 2a) the principal automatic control loops are based on thrust and exit gas temperature. Thrust is derived from the nozzle throat area (A_t) and the stagnation pressure (P_c) at the nozzle entrance, *viz.*, $F \sim P_c A_t$. It is controlled through manipulation of turbopump speed.

Gas temperature (T_c) at the nozzle entrance determines specific impulse (I_{sp}) through the relationship $I_{sp} \sim (T_c/MW)^{1/2}$, where MW is the molecular weight of the

* Other methods of supplying liquid flow considered include: (a) A high pressure liquid tank—the weight and the difficulties of maintaining pressure rule it out as an acceptable source. (b) Use of a hot gas generator to drive the turbine adds an additional control circuit and extra weight. (c) In the "topping" cycle all of the partially heated gas passes through the turbine and then returns to the reactor core. Though potentially lighter than the bleed system and potentially capable of achieving slightly higher specific impulse (I), this system adds some complexity and increases direct interaction between reactor and turbopump.



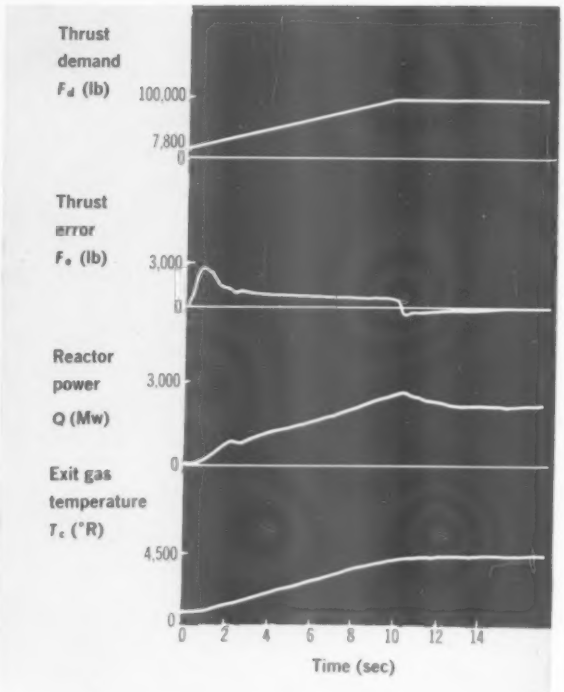


FIG. 3. ENGINE STARTUP calculated (a) for system of Fig. 2a with F and T_c as programmed variables and (b) for simplified system of Fig. 2b in which F_d is sole programmed variable. Errors give difference between demanded and actual values

propellant. A program in which reactor power regulates gas temperature ensures maximum specific impulse without excessive reactor temperature. For dynamic-response reasons and safety considerations subsidiary control loops are closed on pump speed, control rod position and reactor power.

Although in this first study we have treated thrust and temperature commands as independent for illustrative purposes, they are, in fact, not independent for the bleed-cycle engine. First, propellant flow rate interacts with reactor power through the reactivity of the hydrogen in the core. This reactivity varies about as the square of flow rate (for constant power) and may be worth of the order of a few dollars ($1 in $\delta k = 0.0065$). The second interaction comes about through circumscribed navigation on the pump map.

The second control system (Fig. 2b) is a much simpler design in which the reactor is designed so that at rated operating conditions the reactivity loss due to the increase in reactor temperature is exactly balanced by the reactivity of hydrogen present in the core. Here only a thrust control loop is needed—calculations and calibrations guarantee in advance that the reactor temperature will not exceed its bounds. (Some variable reactivity would probably be used to achieve cold critical operation of the reactor, but thereafter this reactivity would not be used in the dynamic control of the engine.)

System Dynamics

The dynamic behavior of an automatic control system is described by a set of differential equations relating its principal components and subsystems. The pertinent equations are given in the box for the two systems studied, with definitions for the symbols. We will discuss in a qualitative way the dynamic behavior of the main components of the two systems.

Heat exchanger. Calculations of the heat exchange in the reactor core are complicated by variations in specific heat with temperature, and the dependence of heat transfer coefficients on temperature and gas flow rate. The problem can be simplified by subdividing the cylindrical core into three or more coaxial stages with two walls each.

A one-stage model of the core (no axial or radial subdivision), however, illustrates qualitatively the dynamics of the heat exchange process (*5*, *6*). If we linearize the equations for small perturbations from steady state operation, we obtain the transfer functions shown in the box. From Eq. 17, given a small step increase in power with propellant flow held constant, the exit gas temperature varies as $(\Delta\dot{Q}/c_p\dot{W}_o)(1 - e^{-t/\tau_h})$. If the power is held constant, Eq. 18 shows that a small step decrease in flow rate produces a step increase in gas temperature of amount $\Delta\dot{W}\dot{Q}_o\tau_2/\tau_h c_p\dot{W}_o^2$ followed by a further rise having the above characteristic exponential behavior.

The thermal time constant τ_h of typical conceptual rocket reactors is of the order of one second. Eq. 19 indicates that τ_h increases with core mass heat capacity and is inversely proportional to propellant flow rate. Thus a fast reactor, with little moderator mass, may have a time constant of a fraction of a second.

Neutron kinetics. Although the reactivity of the hydrogen in the core is positive, its derivative with respect to reactor temperature is negative. This latter fact makes the neutronics heat-exchanger loop inherently stable and gives rise to the second of its two control systems discussed above.

An example will illustrate core response to a change in propellant reactivity: given a step increase in flow (with control-rod reactivity held constant), there is an immediate step decrease in gas temperature, followed by a fairly fast rise in power, which in turn causes a partial recovery (rise) in temperature. The transitions are strongly damped, and both power and temperature are stable at their new equilibrium values.

Turbopump feed system. The liquid hydrogen flow system basically comprises a turbine inlet valve and an axial-flow turbopump. Provided pipe resistance, pipe capacitance, and propellant compressibility are neglected, the system can be represented by a first order differential equation. Pump speed lags behind valve area with a time constant proportional to the moment of inertia of the turbopump rotor divided by the square root of the pump speed (or output flow rate from the pump). The time constant is typically a fraction of a second. The gain of the valve-turbopump combination is proportional to turbine inlet pressure. To provide a control system with over-all dynamic response approximately independent of flow rate, a loop is closed on pump speed in which the loop controller has a gain that increases with decreasing speed (*11*). The response of the turbine inlet valve can be made so fast that it was not included in the study.

Transducers. We assumed thermocouples measure exit gas temperature. Their response lags behind the gas temperature with a time constant that varies directly with the mass of the thermocouple and inversely with flow rate. A typical time constant is a fraction of a second. Lead feedback (with noise filter) to compensate for the lag response provides a fast-acting temperature control loop.

Pressure transducers respond rapidly, have little effect on loop dynamics, and were, therefore, not included in the study.

Subsidiary control loops. A power loop based on the logarithm of power has been found to work satisfactorily throughout the power decades in which there is significant heat generation in the reactor (*12, 13*). Use of the logarithm cancels the customary increase in the gain of the reactor transfer function with power level. The loss in actual power resolution in using the logarithm is not important when the power loop is part of an over-all loop closed on reactor temperature. The bandwidth of the power loop is limited by the bandwidth of the control rod drive mechanism.

Design Conditions for Hypothetical Rocket Engine

Thrust	100,000 lb
Specific impulse (incl. losses)	760 sec
Reactor power	2,260 Mw
Propellant weight flow rate	130 lb/sec
Nozzle entrance stag. press.	1,100 psia
Reactor exit temperature	4,500° R
Reflector entrance pressure	1,220 psia
Nozzle exit pressure	4.0 psia
Nozzle throat area	61 in.²
Nozzle expansion ratio	20
Gas temp. at reflector entrance	120° R
Gas temp. at core entrance	220° R
Neutron mean effective lifetime	1.4×10^{-3} sec
Propellant reactivity	0.0280
Temperature reactivity	−0.0073
Heat-exch. thermal time constant	1.5 sec
Approximate reactor bandwidth (β/l^*)	450 sec^{-1}
Control actuator dynamics, ω_n, ζ	50 sec^{-1}, 0.7
Turbopump speed closed-loop bandwidth	40 sec^{-1}
Controller design (proportional plus integral, $k_p + k_i/s$)	
Thrust Control	
$k_{pF} = 0.001\ sec^{-1}$	$k_{iF} = 0.010\ sec^{-2}$
Temp. Control	
$k_{pT} = 0.009 \frac{\text{Log}_e \text{ Btu/sec}}{^\circ\text{R}}$	$k_{iT} = 0.040 \frac{\text{Log}_e \text{ Btu/sec}}{^\circ\text{R sec}}$
Power Control	
$k_{pp} = 0.640 \frac{1}{\text{Log}_e \text{ Btu/sec}}$	$k_{ip} = 2.00 \frac{1}{\text{sec Log}_e \text{ Btu/sec}}$
Closed Loop Bandwidths	
Thrust: 25 sec^{-1}	Temp.: 20 sec^{-1} Power: 50 sec^{-1}

Control Study Results

The engine hypothesized for the control system study possessed the characteristics given in the table. The reactor was assumed to have U^{235} fuel, graphite moderator and beryllium reflector.

Large-scale transient solutions of the nonlinear equations in the box were obtained from an analog computer, while frequency responses and steady-state solutions were calculated by an IBM-704. Intercomparison of the two calculations led to the elimination of many computational errors. The results presented below are preliminary only in the sense that details of the engine behavior may change somewhat as the characteristics of more individual control components are added to the over-all simulation. We believe that the general behavior of the engine is clearly established.

An example of the operation of the conventional control system, as simulated by the analog computer, is shown in Fig. 3a. Here thrust and temperature are commanded to rise linearly from low to full values in an interval of 10 seconds. Reactor temperature rise is made linear with time to minimize internal thermal stress. The turbopump is brought to full-flow operation along a line of constant specific speed, without using the pump bypass valve. The thrust and temperature errors are seen to be quite small fractions of their ultimate values. Both initial errors (undershoots) last longer than the final error transients (overshoots) because of the increase in many of the system time constants at low propellant flow rate.

Observe that reactor power is a completely dependent variable—it is entirely determined by the input commands to the system, the closed temperature loop and the interaction of the pertinent variables in the core. Although the terminal power overshoot is considerable it has no serious effect on core temperature. During this startup about 850 lbs. of hydrogen were expended to produce an impulse of 5.3×10^5 lb-sec for the rocket stage.

A comparable start-up using the simplified control system is shown in Fig. 3b. With the reactor initially at low power, a command is given for a linear increase in thrust. Propellant reactivity increases the reactor power. Operation stabilizes at full thrust, with final propellant reactivity balancing loss of reactivity from the rise in core temperature. In this mode of operation both reactor power and core temperature are dependent variables. The temperature is seen to rise nearly linearly with time

Control System Mathematics

Nozzle equations: $F = C_f A_t P_c$ (1)

$$I_{sp} = F/\dot{W} \approx \text{constant } (T_c/MW)^{1/2} \quad (2)$$

Heat exchanger:

The i^{th} axial stage is represented by

$$\eta_i'\dot{Q} = W_i'C_i'\frac{dT_{wi}'}{dt} + A_i'h_i'(T_{wi}' - T_{wi}) \quad \text{Ref. 9} \quad (3)$$

$$\eta_i\dot{Q} = W_iC_i\frac{dT_{wi}}{dt} + A_ih_i(T_{wi} - T_{gi}) + A_i'h_i'(T_{wi} - T_{wi}') \quad (4)$$

$$A_ih_i(T_{wi} - T_{gi}) = \dot{W}(H_{oi} - H_{oi-1}) = \dot{W}c_{pi}(T_{oi} - T_{oi-1}) \quad (5)$$

$$T_{gi} = (T_{oi-1} + T_{oi})/2,\ T_{fi} = (T_{wi} + T_{gi})/2 \quad (6)$$

$$h_i = \frac{0.036k_i(Re)^{0.8}(Pr)^{0.4}}{d_1\,(x_i/d_1 + 1)^{0.1}}\left(\frac{T_{gi}}{T_{fi}}\right)^{0.8} \quad \text{(Ref. 10)} \quad (7)$$

where $Re = 4\dot{W}/\mu_i\pi d_1,\ Pr = c_{pi}\mu_i/k_i$

Neutronics: $\rho_i = p_i/Z_iRT_{gi}$ (8)

$$\delta k_p = \sum_i c_{ri}V_i\rho_i \qquad T_{ca} = \sum_i k_{ti}(T_{wi} - T_a) \quad (9,10)$$

$$\delta k_t = c_tT_{ca} \qquad \delta k_c = c_c\sin^2(\theta/2) \quad (11,12)$$

$$\frac{dn}{dt} = \frac{\delta k}{l^*}n = \frac{\beta n}{l^*} + \sum_{j=1}^{6}\lambda_jc_j + \text{source} \quad (13)$$

$$dc_j/dt = (\beta_j/l^*)\,n - \lambda_jc_j \quad (14)$$

$$\dot{Q} = \Gamma n \qquad \delta k = \delta k_p + \delta k_t + \delta k_c \quad (15,16)$$

Heat-exchanger-transfer functions for a one-stage model of the reactor core:

$$\Delta T_c/\Delta\dot{Q} = k_1/(\tau_h s + 1) \quad (17)$$

$$\Delta T_c/\Delta\dot{W} = k_2(\tau_2 s + 1)/(\tau_h s + 1) \quad (18)$$

where

$$\tau_h = WC\,(1/2c_p\dot{W}_o + 1/h_oA + y/k_wA') \quad (19)$$

$$\tau_2 = 0.2WC/h_oA \quad k_1 = 1/c_p\dot{W}_o \quad k_2 = -\dot{Q}_o/c_p\dot{W}_o^2 \quad (20,21,22)$$

Symbols

A	Heat transfer area (in.²)
A_t	Nozzle throat area (in.²)
C	Fuel-moderator specific heat (Btu/lb °R)
C_f	Thrust coefficient
C_j	Concentration of delayed neutrons
c_c	Control reactivity coefficient
c_p	Propellant specific heat (Btu/lb °R)
c_r	Propellant density coefficient of reactivity (lb⁻¹)
c_t	Temperature coefficient of reactivity (°R⁻¹)
d_1	Flow passage diam (in.)
d_2	Outer diameter (in.)
F	Thrust (lb)
H	Enthalpy of propellant (Btu)
h	Heat transfer coefficient (Btu/sec in.² °R)
I_{sp}	Specific impulse (sec)
I_{tp}	Moment of inertia of turbopump (lb in.²)
k	Propellant, thermal conductivity (Btu/sec in. °R)
k_t	Core weighting factor
k_w	Fuel-moderator thermal conductivity (Btu/sec in. °R)
δk	Total reactivity
δk_c	Control-rod reactivity
δk_p	Propellant density reactivity
δk_t	Temperature reactivity
l^*	Mean effective neutron lifetime (sec)
MW	Molecular weight
N	No. of heat-exchanger axial stages
N_{tp}	Pump speed (rpm)
n	Neutron density (neut/in.³)
P_c	Stagnation press. at core exit (psia)

Symbols

Pr	Prandtl number
p_i	Reflector entry pressure (psia)
$\dot{Q}$	Reactor power (Btu/sec)
Re	Reynolds number
s	Laplace transform variable (sec⁻¹)
T_a	Ambient temperature of atmosphere (°R)
T_c	Propellant temperature at core exit (°R)
T_{ca}	Average core temperature (°R)
T_f	Propellant film temperature (°R)
T_g	Average propellant temperature in stage (°R)
T_o	Stage exit gas temperature (°R)
T_w	Stage wall temperature (°R)
t	Time (sec)
V	Volume of core propellant (in.³)
W	Fuel-moderator mass (lb)
$\dot{W}$	Propellant mass flow rate (lb/sec)
y	Thickness (in.)
Z	Compressibility factor
β	Fraction of delayed neutrons
Γ	Conversion factor (Btu/sec/neutrons/in.³)
Δ	Refers to perturbations
ζ	Damping coefficient
η	Part of heat in section
Θ	Control cylinder angular position
λ	Decay constant (sec⁻¹)
μ	Viscosity (lb sec/in.²)
ρ	Propellant density (lb/in.³)
τ	Time constant (sec)
ω_n	Natural frequency (sec⁻¹)

Superscript primes refer to outer radial element.

and to arrive at full value 2–3 sec after full thrust is developed. The lack of a closed temperature loop creates smoother demands on reactor power and makes the power response more sluggish than that of Fig. 3a.

Other phases of the study currently in progress concern transient behavior of the engine while in full operation, and the shut-down programs necessary to preserve the reactor for subsequent use.

* * *

Many persons have contributed in large measure to the work reported herein. The work is an outgrowth of that started by Dr. G. K. Hess, Jr. Valuable suggestions were made by Dr. H. B. Demuth; the analog computer simulation was created by P. B. Erickson and C. E. Stiles; O. A. Farmer developed the IBM-704 code; J. Niedra did preliminary calculations on the thrust and temperature loops; and turbopump analysis was done by E. A. Wheatley, based on information supplied by R. J. Bohl of Rocketdyne. Other members of the Los Alamos Scientific Laboratory Rover controls group, N-4, contributed in ways too numerous to mention individually. Cryogenic properties of hydrogen were supplied by groups CMF-9 and N-1, and reactor design information by groups N-2 and N-3, all of the Los Alamos Scientific Laboratory.

BIBLIOGRAPHY

1. H. P. Smith, A. H. Stenning. "Dynamics and Control of Nuclear Rocket Engines," Ph. D. Thesis (M.I.T., 1960) unpublished
2. B. R. Felix, R. J. Bohl, Dynamic analysis of a nuclear rocket engine system, *Am. Rocket Soc. J.* **29,** No. 11, 853 (1959)
3. G. F. Wislicenus, "Fluid Mechanics of Turbomachinery" (McGraw-Hill Book Co., Inc., New York, 1947)
4. M. J. Zucrow, "Aircraft and Missile Propulsion" (John Wiley and Sons, Inc., New York, 1958)
5. R. R. Mohler, "Stability and Control of Nuclear Rocket Propulsion," IRE Preprint 60AC8 (1960)
6. G. K. Hess, private communication (1959)
7. M. A. Schultz, "Control of Nuclear Reactors and Power Plants" (McGraw-Hill Book Co., Inc., New York, 1955)
8. G. R. Keepin, T. F. Wimett. Reactor kinetic functions—a new evaluation, NUCLEONICS **16,** No. 10, 86 (1958)
9. W. H. McAdams, "Heat Transmission" (McGraw-Hill Book Co., Inc., New York, 1942)
10. L. V. Humble, et al., "Measurements of Average Heat Transfer and Friction Coefficients for Subsonic Flow of Air in Smooth Tubes at High Surface and Fluid Temperatures," NACA Report 1020 (1951)
11. R. J. Bohl, private communication (1960)
12. R. E. Finnigan, "The Tory II Control System: Description, Design, and Selection of Components," UCRL-5465 (University of California Report, 1959) unpublished; R. E. Finnegan, "Control Concepts for Nuclear Ramjet Reactors," I.R.E. paper no. 60AC-7 presented at Joint Automatic Control Conference (M.I.T., September, 1960)
13. E. A. Brown, private communication (1960)

High-Temperature Materials for Rocket Reactors

AUTHOR

***Donald P. MacMillan** is leader at LASL of the group studying high-temperature materials problems in the Rover program. He organized the group in 1955 when the Nuclear Propulsion Division was formed. MacMillan has been at LASL since 1944 and for several years was a group leader in the Weapons Divison.*

IN THE DEVELOPMENT of nuclear-powered rocket engines, the boundaries of engineering design are set, even more inexorably than in lower-temperature reactors, by the properties of available materials. Material problems arise in connection with all parts of a fission-powered rocket reactor, i.e., fuel elements, structural materials, control rods, moderator, reflector, etc. However, the most critical components are the fuel elements. The following discussion considers problems pertinent to the Rover-type reactor—solid fuel elements and gaseous working fluid.

Neutron Absorption

The neutron absorption of the materials that are sufficiently refractory (capable of withstanding high temperatures) to be useful for fuel elements varies so widely that a reactor concept that is feasible with one material may be useless with another.

It is customary to distinguish between the thermal-neutron-absorption cross section and the resonance-absorption integral, which is a measure of the absorption of epithermal and higher-energy neutrons. To take one extreme, the thermal-neutron-absorption cross section of carbon is very small (0.0045 barns), and the resonance-absorption integral is zero barns. Such a material, which is also a good moderator, can readily be used in a homogeneous reactor design.

This is not the case with natural tungsten (containing the naturally occurring mixture of isotopes 180, 182, 183, 184, 186), whose thermal-neutron-absorption cross section is 19 barns and resonance-absorption integral about 450 barns. These quantities are so large that natural tungsten appears impractical for a homogeneous reactor other than a fast reactor. The designer is therefore forced to an inhomogeneous structure in which neutrons can be moderated in regions which do not contain large amounts of tungsten. Thus the realization of an epithermal reactor using tungsten appears difficult while with graphite it does not appear difficult.

In principle, the problems of design with tungsten could be greatly alleviated by using tungsten-184, which constitutes almost one-third of natural tungsten and whose thermal-absorption cross section is about 2 barns.

Tantalum has about the same neutron-absorption characteristics as natural tungsten, while niobium (columbium) and molybdenum have much smaller absorption cross sections and zirconium cross sections are two orders of magnitude smaller.

Radiation Damage

Since the core material in a nuclear rocket reactor must withstand a radiation field unmatched by any existing power reactor, it might be expected that radiation damage would present problems. However, while the flux in a rocket reactor must be in excess of 10^{16} neutrons/cm^2/sec, the operating life of the rocket reactor is short so that the integrated lifetime flux, nvt, is at least one and perhaps two orders of magnitude less than in, e.g., ETR. Furthermore, it appears that at fuel-element temperatures a large part of radiation damage may be expected to anneal out.

Radiation-damage problems to the core of rocket reactors may therefore hopefully be expected to be less severe than in reactors operating at more modest temperatures.

Compatibility with Gas

The specific impulse of a rocket engine depends not only on the temperature to which the working fluid is heated, but also is roughly proportional to the square root of the reciprocal of the mean molecular weight of the gas as it enters the nozzle.

The chemical rocket engine depends on the reaction of an oxidizer and fuel for energy production, and one must perforce accept the combustion products produced, such as water, carbon monoxide, carbon dioxide and nitrogen. The mean molecular weight of these products is near 20.

In the case of the heat-exchanger nuclear rocket, in which there is some freedom of choice of working fluid, hydrogen is an obvious choice. Therefore, the fuel element must at least be compatible with hydrogen. If it is desired to use, instead of pure hydrogen, some compound or mixture which will pyrolyze to give a low-molecular-weight gas which is predominantly hydrogen, the fuel element must in addition be compatible with the other products of pyrolysis. This might for example be nitrogen, if the stored propellant were ammonia.

The compatibility requirements of rocket reactors differ sharply from those of the Aircraft Nuclear Power project and the Pluto nuclear ramjet where compatibility with air is one of the principal problems. Unfortunately, hydrogen is not chemically inert at temperatures of interest for rocket engines.

Mechanical Properties

The support of a fuel element and its retention in position against the forces of the gas stream impose some minimum requirement for mechanical strength.

While metals are generally well behaved under either tensile or compressive stress, compounds such as the refractory carbides generally behave as brittle substances which may be expected to show good behavior under compressive stress but are unlikely to tolerate tensile stress. In general the behavior of these materials depends strongly on strain rate, fracture occurring easily at high rates.

The specific impulse obtained in a rocket motor is roughly proportional to the square root of the absolute

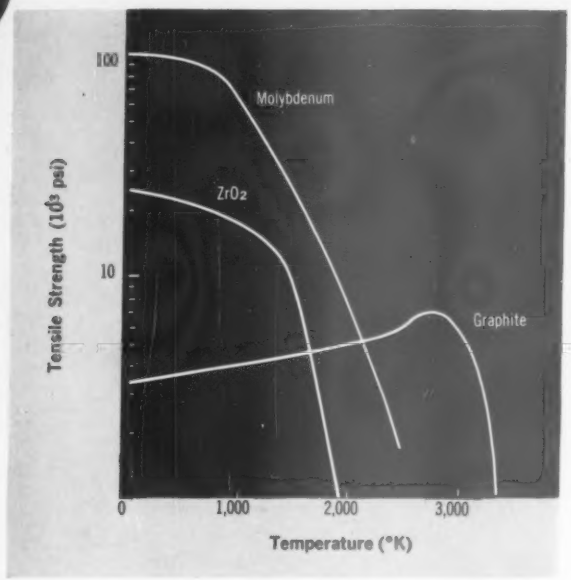


FIG. 1. GRAPHITE strength increases with temperature to exceed strength of most refractory metals at high temperatures

temperature of the gas entering the nozzle. Thus, fuel elements must operate at as high a temperature as possible. As temperature increases, the number of elements and compounds remaining solid, from which one may choose materials for fuel elements, decreases rapidly—only about fifty remain solid above 2,500° C and about 20 above 3,000° C. Furthermore, these do not include well known materials but are in general the relatively unknown "exotic" substances.

Possible Materials

Potential fuel-element materials can be classified in three groups: (a) graphite, (b) metals and (c) "ceramics." These classes differ sharply in their properties. While design can minimize the strength required of a fuel element, the mechanical characteristics of the material have a large effect on how it can be used.

Refractory metals are characterized by high tensile strength at moderate temperatures and high melting points. They lose strength progressively, however, as temperature is raised and, long before the melting point is reached, become so soft that the creep properties become a more meaningful criterion than ultimate tensile strength.

In contrast to the metals, graphite, which at ordinary temperatures is not strong compared to metals, increases in strength with temperature to about 2,500–2,600° C where it is almost twice as strong as at room temperature (Fig. 1). At this temperature its strength is of the same order as tungsten, the most refractory of the common metals. Above 2,700° C, graphite becomes progressively more plastic but remains solid to its sublimation point ($\sim$ 3,925° C at atmospheric pressure).

The third group of refractories, the ceramics, are interstitial compounds including carbides, nitrides and borides of some of the transition metals of the fourth, fifth and sixth groups of the periodic table. These materials are characteristically hard and strong but brittle at moderate temperatures.

Refractory Metals

Metals whose melting points are high enough to be of interest include tantalum, niobium, molybdenum, tungsten, rhenium, osmium and ruthenium. They are expensive, scarce and hard to fabricate. Tantalum and niobium absorb hydrogen and become brittle at 350–650° C. Consequently, the only practical refractory metals are tungsten and molybdenum.

Tungsten and molybdenum recrystallize at a low fraction of their melting point, which complicates their use. For example, a 1-mil molybdenum foil, initially fibrous and tough, recrystallizes completely in 20 min at 1,800° C (Fig. 2a) and becomes brittle. The onset of recrystallization can be somewhat delayed both in rate and temperature by "doping." A "doped" molybdenum foil, which was also heat-treated for 20 min at 1,800° C, retains its original fibrous structure almost unchanged (Fig. 2b). However, if the treatment temperature is raised to 2,000° C, grain-growth restraint fails (Fig. 2). Thus the maximum working temperature might be taken to be 1,800° C, less than 70% of the melting point (2,650° C).

A great deal more study of the physical properties of refractory metals is needed. However, substantial contributions to the knowledge of the creep properties of tungsten and molybdenum have been made recently. Green studied the creep-rupture behavior of commercial

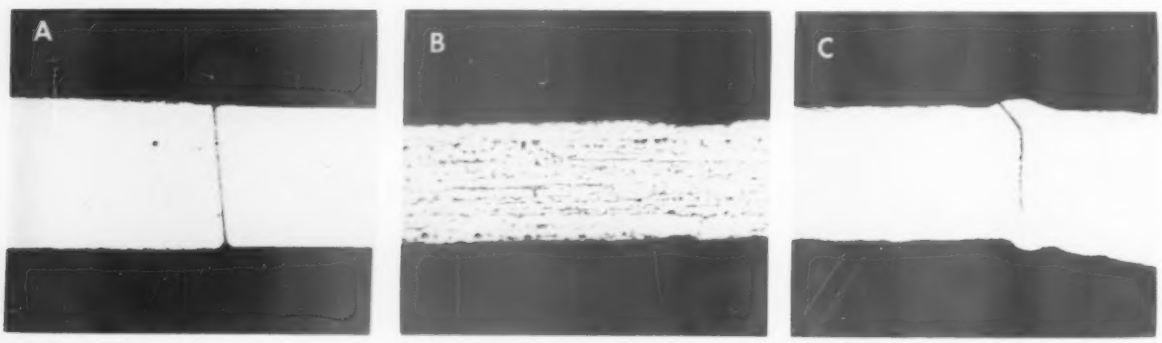


FIG. 2. MOLYBDENUM recrystallizes below melting point. Cross sections shown are 0.001-in.-thick foil heat-treated for 20 min: (a) pure Mo completely recrystallizes at 1,800° C; doped Mo is (b) fibrous at 1,800° and (c) recrystallized at 2,000°

powder-metallurgy tungsten rod (*1*). The logarithm of stress versus logarithm of rupture time (Fig. 3) was found to be linear. Also, the logarithm of creep rate is a linear function of the logarithm of the initial stress. Green went on to study the Zener-Holloman temperature-compensated creep-rate parameter and found that the Larson-Miller parameter, Z, is a linear function of the logarithm of initial stress. A similar study was made of molybdenum. In such studies for nuclear rocket application, it is noteworthy that times of interest are short compared to the hundreds or thousands of hours familiar in ferrous metallurgy.

Uranium is only slightly soluble in molybdenum and tungsten. Of the refractory uranium compounds that might be used, uranium carbide has the disadvantage that it reacts with tungsten to form a liquid phase near 2,500° C. Uranium dioxide does not react with tungsten. The vapor pressure of UO_2, however, is appreciable, and at temperatures of interest it would have to be confined to prevent substantial losses.

Ceramics

The refractory "ceramics" of interest are interstitial compounds of transition metals of groups four, five and six of the periodic table. In these compounds the small nonmetallic atom, which may be boron, carbon or nitrogen, occupies interstices of the metal lattice. This is generally possible when the ratio of radius of nonmetallic to metallic atoms is 0.59 or less (Hägg's rule) (*2*).

The composition of the ceramics is not fixed but variable over a range. These substances very commonly do not evaporate congruently, i.e., the material lost by evaporation does not have the same composition as the remaining material. Thus, the composition—and properties—of the residue changes continuously. Furthermore, different compounds are subject to this effect to varying degrees. At one extreme, for example, is TaC which loses carbon preferentially by evaporation, and if time and temperature are great enough, apparently tends toward complete loss of carbon. At the opposite extreme is ZrC, which evaporates congruently.

An important consequence of static thermal gradients in solid materials is the accompanying thermal stress. The huge thermal gradients in nuclear-rocket fuel elements can create thermal stresses sufficient to exceed the strength of the material if not relieved by creep. In general, the interstitial compounds have not been extensively studied, and their mechanical properties are not well known. However, it is commonly pointed out that the thermal-stress resistance of these materials, based on room-temperature parameters, is substantially less than that of graphite or the refractory metals. This is based on some measure of thermal-stress resistance such as the expression

$$M \approx ks/\alpha E$$

where M is a measure of the thermal stress resistance, k is the thermal conductivity, s is tensile strength, α is the thermal-expansion coefficient and E is Young's modulus. For example, M is about 30 for Ta and > 100 for graphite, while for TaC it is probably about 3. The thermal-shock and thermal-stress resistance of the interstitial compounds, however, depend strongly on "processing variables," e.g., particle size, distribution and degree of compaction.

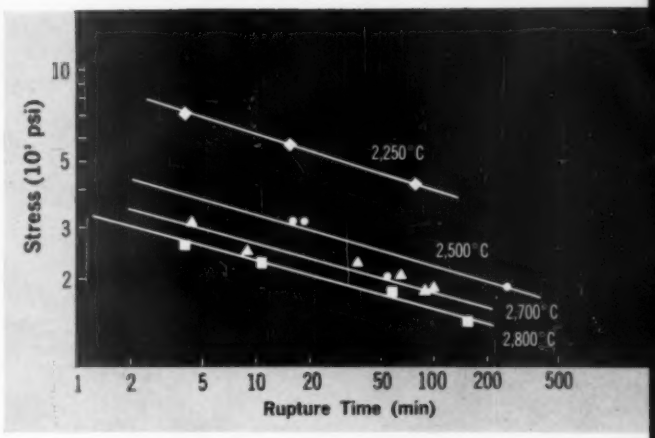


FIG. 3. TUNGSTEN-ROD rupture tests show linearity

Because of the enormous energy density required of rocket engines if an acceleration in excess of 1.0 g is to be realized, the thermal conductivity of fuel elements must be good to avoid ruinous thermal gradients. The bulk power density of nuclear rocket engines for ground take-off must be of the order of 100 Mw/ft³ or 3.5 kw/cm³.

As an illustration of this, consider a niobium carbide fuel element. The melting point of NbC is about 3,500° C, which appears attractive. Let us suppose, however, that the fuel element needs to be $\frac{1}{8}$ in. thick and must contain 20 mol% UC. To begin with, the melting point of UC is only 2,350° C. The NbC and UC are mutually soluble in the solid state and we can crudely estimate by proportion that the melting point of the UC-NbC would be about 3,230° C. Since the bulk power density of the reactor must be about 100 Mw/ft³, the heat flux through the fuel-element surface will be $\sim 2 \times 10^6$ Btu/hr/ft². The temperature difference between centerline and surface of a flat, semi-infinite plate is given by

$$\Delta T = Qt^2/8k$$

where Q is the bulk power generation, t is the plate thickness and k the thermal conductivity. For the sake of illustration, the thermal conductivity of the fuel-element material will be taken to be 8 Btu/hr/ft/° F. This leads to a surface temperature of 2,915° C. If we allow 10% for fabrication variables (e.g., uniformity of uranium loading and heat generation), the maximum surface temperature of the fuel element must be reduced to 2,625° C. Let us now suppose that it is not practical to bring the gas temperature closer than 100–150° C to the plate-surface temperature. Then, the gas temperature is $\sim$ 2,500° C, 1,000° C below the melting point of the basic fuel-element matrix material.

Graphite

At ordinary reactor temperatures the design engineer is usually concerned with the tensile strength and yield strength of materials. Since the life required of a rocket reactor is measured in minutes rather than in hundreds or thousands of hours, and because temperature is pushed to the point where materials become plastic, creep properties, such as the creep rate and the time for creep to rupture,

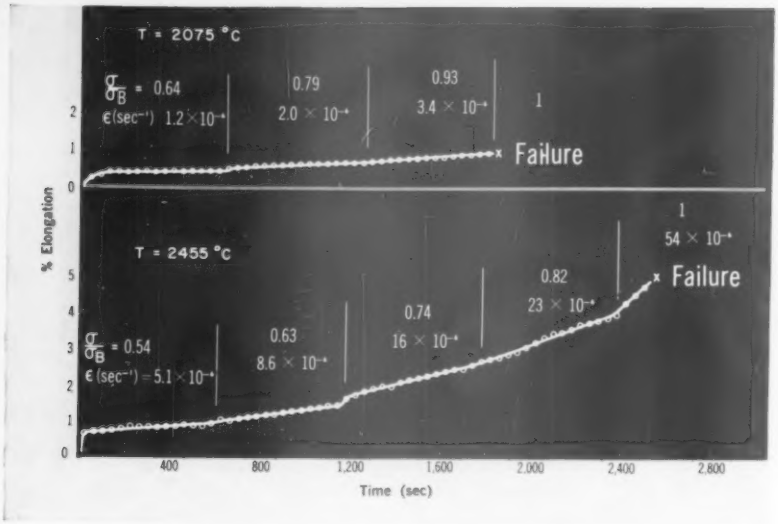


FIG. 4. LDC GRAPHITE ($1\frac{1}{4}$ gm cm^3 U) tests show tension creep rate increases with temperature and applied stress. Stress is expressed as σ/σ_B where σ_B is breaking stress and σ is any other stress value; ϵ is $\Delta L/L$ per second where L is specimen length

are of greatest importance. Figure 4 (*3*) shows that the tension creep rate increases with both temperature and applied stress. Similar effects occur under compressive stress (*4*). Clearly, graphite exhibits appreciable plasticity at high temperature. The measurement of graphite properties is complicated by the anisotropy of the material which results basically from the anisotropy of the solid particles of filler material used in graphite manufacture.

Graphite has the disadvantage that it is attacked by hydrogen at a rate that becomes appreciable above 1,500° C and increases rapidly with temperature (Fig. 5). Also, evaporation becomes more important at 2,700° C although graphite never melts at atmospheric pressure.

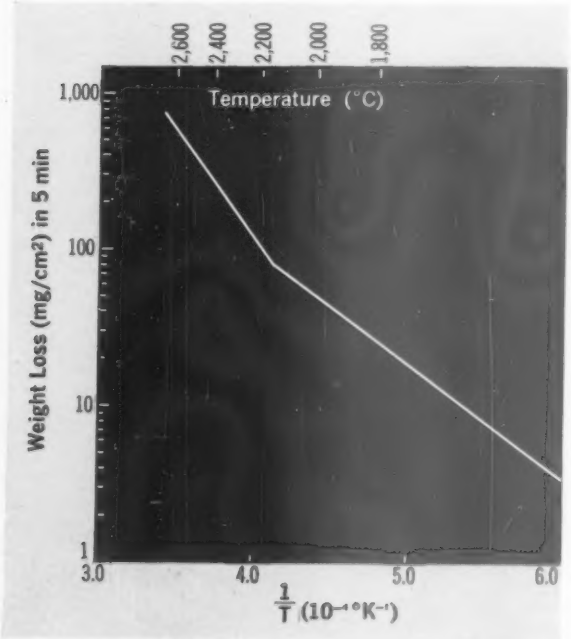


FIG. 5. TYPICAL RAPID INCREASE of corrosion rate with temperature of commercial-grade graphite; hydrogen flow rate is 5×10^4 lb/ft^2/hr

To a limited degree, graphite can be protected from corrosion by a coating that is not attacked by the gas. This may be one of the very refractory interstitial compounds. Reaction of the coating with the graphite would in a sense be avoided if the coating were itself a carbide. However, carbon is soluble to a greater or lesser degree in the refractory carbides at temperatures of interest in a nuclear rocket engine, with the effect that the melting point of the carbide coating is reduced. This effect can be very large, e.g., ZrC melts in the pure state at 3,500° C but, when saturated with carbon, at about 2,850° C. It must also be expected that uranium will enter the coating from the graphite and, since the melting point of uranium carbide is about 2,350° C, this will further lower the melting point and affect other properties of the coating. Of course, there are the further difficulties of obtaining a uniform coat and assuring its perfection.

Environmental testing of materials under conditions simulating all but the rocket radiation field can usually be accomplished using electric heating. Materials can be irradiated in a reactor such as MTR or ETR to the total dose expected in a rocket reactor. Even such reactors as these, however, fall short of the dose rate of a rocket reactor by one or more orders of magnitude.

The final test of performance of materials under environmental conditions is to carry out material tests in the rocket reactors themselves. This necessitates recovery of samples from the reactor after test completion. To accomplish this, a hot-cell facility has been built at the Nevada Test Site where these reactor tests are carried out.

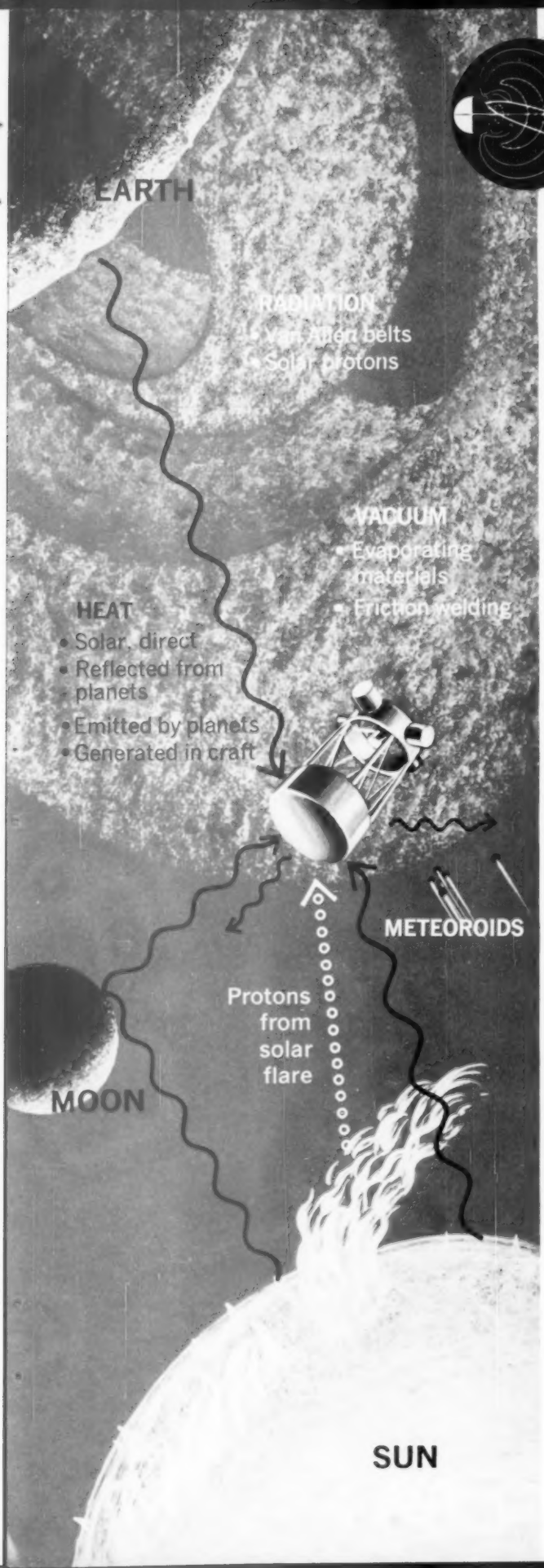
The investigation of material properties above 2,000° C is in a comparatively primitive state at present. Progress in this temperature region depends largely on the accumulation of basic information about refractory materials and growth of our high-temperature engineering capability.

* * *

This work was done under the auspices of the U. S. Atomic Energy Commission.

BIBLIOGRAPHY

1. W. V. Green, *Trans. Met. Soc. of AIME* **215**, 1057 (1959)
2. P. Schwartzkopf, R. Kieffer, "Refractory Hard Metals," p. 12 (Macmillan Co., New York, 1953)
3. P. Wagner et al., *J. Appl. Phys.* **30**, 152 (1959)
4. P. Wagner, A. R. Driesner, *J. Appl. Phys.* **30**, 148 (1959)



Space Environment

SECTION IV—*Spacecraft will encounter a variety of environmental extremes on their journeys through the solar system (see left), including bombardment by meteoroids and high-energy protons and electrons, wide variations in ambient radiation heat flux and ultra-high-vacuum materials problems*

Space Radiation Levels

By JOHN E. NAUGLE

National Aeronautics and Space Administration, Wash., D.C.

THE CHARGED-PARTICLE radiation in space can be divided into three main categories: galactic cosmic rays, Van Allen radiation and sporadic but very intense solar proton beams. These categories depend on the spatial distribution of the particles and their flux variation with time.

In space, beyond the influence of the geomagnetic field, the flux of galactic cosmic rays is independent of spatial position and, to within a factor of two, also independent of time. The Van Allen radiation is trapped in a doughnut-shaped region centered over the geomagnetic equator. This region breaks down into two zones: an inner zone in which the particle density appears to be constant in time, and an outer zone where the intensity can vary by several orders of magnitude depending on solar activity. The intensities of solar particles in the outer zone are correlated with major solar flares that last from 10 to 100 hr.

Of these three radiation-level categories, the sporadic but intense solar-proton beams present the major hazard to manned space flight outside the protection of the earth's magnetic field. Although the radiation levels due to these particles are formidable, by making flights at times when the probability of a flare occurring on the sun is small and by using fuel and other equipment in the spacecraft for shielding, one can protect astronauts from undesirable radiation effects. In addition, since flares are observed on the sun 30 min to several hours before the protons begin to bombard the earth, additional shielding precautions can be made during this time on manned spacecraft.

Van Allen Radiation

In the inner Van Allen zone the radiation environment is dominated by large numbers of protons with energies > 10 Mev. In the outer region electrons with energies < 1 Mev predominate; there are few if any protons with energies > 30 Mev (Table 1) (*1*). The integral energy spectrum for protons in the inner zone is $N(>E) = K/E^{0.84}$ protons/cm²/sec/ster. ($E > 75$ Mev, K is number of protons) (*2, 3*). Between energies of 10 to 20 Mev the integral spectrum in emulsions exposed at 1,890 km

TABLE 1—Van Allen's Estimate of Particle Flux

Particles	*Energy*	*Intensity*
	Heart of Inner Zone (3,600 km on geomagnetic equator)	
Electrons*	>20 kev: max	$\sim 2 \times 10^9$/cm²/sec/ster
Electrons†	>600 kev: max	$\sim 1 \times 10^7$/cm²/sec/ster
Protons†	>40 Mev: max	$\sim 2 \times 10^4$/cm²/sec
	Heart of Outer Zone (16,000 km on geomagnetic equator)	
Electrons‡	>20 kev	$\sim 1 \times 10^{11}$/cm²/sec
Electrons	>200 kev	$\lesssim 1 \times 10^8$/cm²/sec
Protons	>60 Mev	$\lesssim 10^2$/cm²/sec
Protons	<30 Mev	no information

* Accuracy within a factor of 10.
† Accurate to factor of 2.
‡ Theoretical considerations indicate this value may be too large.

varies as $E^{-3.5}$ (*3a*).

Studies with Explorer IV of the geographic position and intensity variation of the inner zone show that its lower edge is 400 km high at 300° E longitude and ~1,300 km at 100° E (*4*). This variation arises because the radiation belt is symmetric to the geomagnetic axis, offset 340 km from the axis of the earth. Beginning at the lower edge of the belt the omnidirectional flux of 30-Mev protons rises rapidly from 2 to ~600 protons/cm²/sec in the first 400 km and levels off at 2×10^4 protons/cm²/sec at 3,600 km.

The flux and energy spectrum for the electrons in the zones is not yet very well known. The integral energy spectrum is: $N(>E) = K/E$ electrons/cm²/sec (γ is 4–5, $E > 200$ kev (*5, 6*).

Solar Proton Beams

Analysis of ionospheric data taken during the great solar flare of February 23, 1956 showed an abnormal amount of ionization in the D layer (lowest ionized layer in mesosphere) between ~30 and 100 km over the polar regions (*7*). Continuous monitoring of D-layer ionization with riometers since 1957 has detected ~36 additional cases of such high-ionization levels (*8–10*). Balloons, satellites and rockets during these events show that the ionization is from protons with energies of ~100 Mev (*11–14*).

Although the flux, energy spectrum and duration of these proton beams vary from event to event, they all seem to follow this sequence of events (*15*):

- First a major solar flare occurs with importance* 2^+ to 3^+. Quite frequently, as in the events of July 1959, there are several flares within 3 or 4 days in the same disturbed area of the sun. Type IV radio noise and soft X-rays frequently accompany the visible flare.
- After an interval that varies from 30 min to several hours, protons with energies from a fraction of an Mev up to several hundred Mev are observed over the polar regions. Riometers record these as a large, varying attenuation of cosmic radio noise lasting a few hours to 100 hr.
- Balloon, rocket and satellite measurements show that the flux increases for 5–10 hr after the flare occurs before it reaches a maximum and starts to decrease. These measurements indicate that the particle integral energy spectrum is $N(>E) = K/t^n E^{\gamma(t)}$ particles/cm²/sec (t is time measured from time that flux reaches maximum value; N is ~2–3; E is energy in Mev; γ varies from 5–2 during one event or from event to event.)
- As predicted by the Stoemer theory, during the first 24–30 hr the protons are confined to geomagnetic latitudes > 60°. After this time the plasma cloud ejected by the sun strikes the earth and disturbs the earth's magnetic field. Particles are observed in geomagnetic latitudes below those predicted from the measured particle-energy.
- Although on at least one occasion alpha particles have been observed (*16*), the beam consists primarily of protons. In two events particles with atomic number ≥3 have been observed (*16a*).
- Although almost all the observed solar-proton events in the atmosphere have been correlated with flares on the visible surface of the sun, 3 or 4 events have recently been observed that are not related to visible flares. The most recent event was observed November 20, 1960 (*17*).

The outbursts of solar protons occur at random. At present, we cannot predict with certainty when such an event will take place; by observing solar activity, however, we can state that there is a great or small probability of an event within 4 or 5 days of the time of observations. Anderson has worked out an effective prediction method based on the size of the penumbra of sunspots (*18*).

What the future holds. The outlook for additional data in the near future is very good. Balloons, rockets and satellites have obtained data simultaneously on the flares that occurred September 4 and November 12, 1960. After the data from these flares have been analyzed, however, the likelihood of getting additional data before 1967 is remote. Since these events are correlated with solar activity they occur about once each month at the peak of the 11-yr solar cycle. However, only one or two flares can be expected each year in the minimum solar period from 1961 to 1967.

TABLE 2—Radiation Levels and Shielding in Space

Radiation Levels	
Typical exposures	*Dose rate*
Normal radiation level (sea level)	0.001 rem/day
Interplanetary space (cosmic rays)	5–12 rem/yr
Heart of inner belt (protons)	20 rem/hr
Heart of outer belt (electrons, X-rays)	200 rem/hr
Solar Event:	
Range of peak levels	10–100 rem/hr
Range of total exposures	2–400 rem

Shielding Requirements for a Major Solar Flare

Thickness (g/cm^2)	*Weight of sphere: 5-ft inner radius* (*Lb*)	*Integrated dose* (*rem*)
10.0	7,000	100
16.0	11,000	25
30.0	21,000	3

Shielding Requirements

The amount of shielding needed in space is a complex function of the dose allowed an astronaut, the trajectory through the radiation belts and the flux, energy spectrum and duration of any solar photon events (*19–22*). Table 2

* Importance classes of 1, 2 or 3 indicate the area of the solar disk covered by a flare. A class 1 flare covers one ten thousandth of the solar disk; a class 3 flare covers 3 ten thousandths. A plus or minus sign indicates the flare brightness or intensity.

gives radiation levels and estimated shielding thicknesses and weights of carbon that reduce the total dose during a major solar flare to values of 100, 25 and 3 rem. This shielding data is based on information from the May 10, 1959 flare taken after it had reached its maximum. The estimates take into consideration only the primary particles from the flare; secondary particles may also affect the dose. Preliminary estimates show that if the best use is made of fuel and other materials ~8 gm/cm² shielding will be used on crafts like Apollo.

Depending on the method by which the intensity is extrapolated back to the time of the flare, total dosage as a function of shielding thickness may vary by 10 (Table 2).

BIBLIOGRAPHY

1. J. A. Van Allen, *J. Geophys. Research* **65,** 1377 (1959)
2. S. C. Freden, R. S. White, *Phys. Rev.* **3,** 9 (1959)
3. S. C. Freden, R. S. White, *J. Geophys. Research* **65,** 1399 (1960)
3a. C. E. Fichtel, D. E. Guss. Program Abs. Amer. Geophys. Union (2nd Annual Meeting, 1961)
4. S. Yoshida, G. H. Ludwig, J. A. Van Allen, *J. Geophys. Research* **65,** 807 (1960)
5. M. Walt, et al. Energy spectra and altitude dependence of electrons trapped in the earth's magnetic field, in "Space Research," p. 910, (North-Holland Publishing Co., Amsterdam, 1960)
6. S. N. Vernov, A. E. Chudakov. Terrestrial corpuscular radiation and cosmic rays, in "Space Research," p. 751 (North-Holland Publishing Co., Amsterdam, 1960)
7. D. K. Bailey, *Proc. I. R. E.* **47,** 255 (1959)
8. G. C. Reid, H. Leinbach, *J. Geophys. Research* **64,** 1801 (1959)
9. T. Obayashi, Y. Hakura, *J. Geophys. Research* **65,** 3131 (1960)
10. B. Hultqvist, J. Ortner, *Nature* **183,** 1179 (1959)
11. K. A. Anderson, *Phys. Rev.* **1,** 335 (1958)
12. K. A. Anderson, et al., *J. Geophys. Research* **64,** 685 (1959)
13. P. S. Freier, E. P. Ney, J. R. Winckler, *J. Geophys. Research* **64,** 685
14. E. P. Ney, J. R. Winckler, P. S. Freier, *Phys. Rev.* **3,** 183 (1959)
15. J. R. Winckler, paper presented at Radiation Research Society Symposium on Radiation in Space (May, 1960)
16. P. S. Freier, paper presented at the Midwest Cosmic Ray Conference (Iowa City, Iowa, October, 1959)
16a. D. A. Kniffen, J. E. Naugle. Program Abs. Amer. Geophys. Union (2nd Annual Meeting, 1961)
17. K. A. Anderson, D. C. Enemark, *J. Geophys. Research* **65,** 2657 (1960)
18. K. A. Anderson, private communication
19. R. I. Allen, et al. "Shielding Problems in Manned Space Vehicles," Semiannual Technical Summary Report, Contract-DA-01-009-506-ORD-832 (Lockheed Nuclear Products)
20. D. H. Robey, *Astronautica Acta* (1960)
21. T. G. Barnes, E. M. Finkelman, A. L. Barazotti, paper presented at American Astronautical Society Flight Symposium (Dec. 27, 1960)
22. G. J. Jacob, ed. Proceedings of Conference on Radiation Problems in Manned Space Flight. NASA-D-588 (1960)

Meteoroid Hazard to Nuclear Spacecraft

By ROBERT L. BJORK, *Rand Corporation, Santa Monica, California*

How do particle (meteoroid) impacts in space affect nuclear-powered space systems? This problem, which designers must solve, is complicated by the lack of accurate, direct observations of meteoroid masses, densities and velocities; consequently, it is hard to find how deeply and how often meteoroids penetrate spacecraft.

Preliminary designs indicate that the waste-heat radiator is the part of a nuclear-powered system most vulnerable to the punishing impacts of meteoroids because it needs more weight than any other part to armor properly. As one increases the power, the weight penalty becomes worse (*1, 2*). (See p. 63.)

In calculating the meteoroid hazard, one must collect and analyze available experimental data about large meteoroids recorded by photographic or radar techniques as well as about the tiny meteoroids that hit detectors in satellites and rockets. Combining this information with experimental and theoretical data on hypervelocity impacts, one can estimate how deeply and how often meteoroids penetrate different materials in space.

Meteoroid Flux

One wants to know meteoroid flux φ (particles/m²/sec) as a function of mass. ϕ is the rate at which *all* particles greater than mass m strike a surface. Since flux is not accurately known for all masses, one plots flux and mass data accumulated by photographic, radar and satellite observations on a graph (Fig. 1) and fits it with a curve. One finds that the curve has the form $\varphi = 10^{-12}\, m^{-1.34}$ (mass m is measured in grams). This curve is the best estimate of meteoroid flux as a function of mass.

The best quantitative observations of the meteroid flux that bathes the earth have been made from ground stations by photographic (*3–6*) and radar (*5, 7–10*) apparatus and by microphonic plates carried aloft in rockets and satellites.

The photographic and radar techniques survey vast areas of the sky continuously and measure the small particle flux massive enough to be detected from the earth. Observations show that the bright photographic meteors have very low densities—~0.05 gm/cm³. Radar measurements record slightly fainter, denser meteoroids.

Both methods give a meteor velocity range of 11–72 km/sec. The average velocity is ~30 km/sec.

Rockets and satellites, on the other hand, record only tiny meteoroids ($\leq 10^{-8}$ gm) that hit a small sensitive detector over a period of a few days to several weeks. Data from Explorer I (*12, 13*) and Vanguard III overshadow the rest in statistical significance (Fig. 1).

Variations in flux. Since the photographic, radar and satellite data are recorded in the vicinity of the earth or on it, one must consider that the earth shields the detecting device from the meteoroid flux in one direction. Therefore as one goes a few earth radii into space, the flux should double. Two recent investigations, however, tentatively conclude that very small meteoroids measured by satellites are in closed orbits around the earth (*14*). If this is true, the meteoroid flux decreases as one goes out in space. Hibbs' work indicates that between 500 to 3,000 km altitudes flux varies inversely as the distance from the earth's center squared. Whipple concludes that over a greater range the variation is as the inverse 1.4 power of distance.

Meteor Penetration

Since particles of well defined mass have not yet been accelerated to meteoric velocities in the laboratory, we have no direct experimental evidence of how deeply high-velocity particles penetrate into targets and therefore how much shielding must be used against meteoroids. Consequently, we must calculate the penetration theoretically.

We calculated sizes of craters made in thick steel and

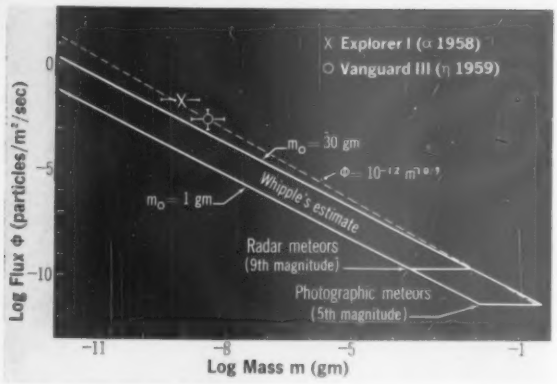


FIG. 1. METEORIC FLUX as a function of mass shows Whipple's calculated estimate of flux for zero magnitude meteors and points plotted from meteoroid impact data recorded in Explorer I and Vanguard III

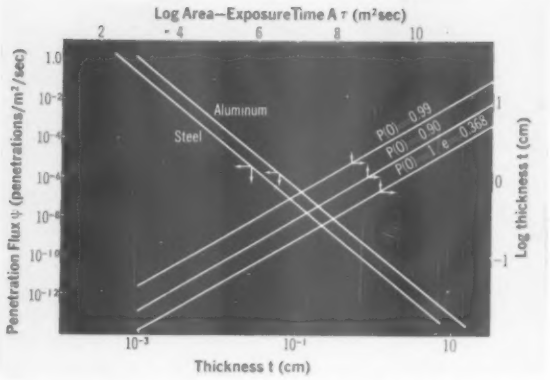


FIG 2. GRAPH SHOWS CALCULATED FREQUENCY with which steel and aluminum sheets of thickness t are penetrated by meteoroids (left and bottom axes). It also gives (top and right axis) aluminum thickness needed to protect radiators from flux

aluminum targets by projectiles of the same material (*15*). The projectiles were assumed to hit the targets at right angles with velocities of 5.5, 20 and 72 km/sec. Our calculations agree in both size and shape with the hemispherical experimental craters made in aluminum at 6.3 km/sec and in iron at 6.8 km/sec (for pressures developed in impacts, iron and steel behave identically). Our calculations indicate that for aluminum projectiles hitting aluminum targets, the penetration depth is $p = 1.09\,(mv)^{1/3}$ and for iron on iron $p = 0.606\,(mv)^{1/3}$ (p is in centimeters; m, projectile mass, is in grams; v, impact velocity, is in km/sec).

Laboratory impact data shows that the greater the density of a particle, the deeper will be its penetration (*16*). Specific gravities of small meteoroids appear to approach that of stone. Since specific gravities for stone, aluminum and steel are 2.8, 2.7 and 7.0, the aluminum-projective equation gives good values for meteoroid penetration in aluminum shielding; the steel-projectile equation overestimated penetration in steel.

Frequency of penetration. By combining the equation for meteoroid flux with that for penetration, one can calculate the frequency with which a metal plate in space will be punctured (Fig. 2). The meteoroid punctures follow a Poisson probability distribution. $P(n) = (\psi A\tau)^n e^{-\psi - A\tau}/n!$ [$P(n)$ is probability of n punctures in sensitive area A exposed for time τ. ψ is average number of punctures/m²/sec.] If one chooses $P(0)$, the probability that no punctures occur, the skin thickness t needed for protection comes from the penetration equation together with Fig. 2. Figure 2 also shows some representative values that pertain to aluminum shielding.

Shielding for Radiators

Our calculations give the amount of shielding material needed to protect radiators from meteoroids. The whole radiator is not sensitive to meteoroid penetration; only the area containing the tubes that circulate the working fluid must be protected. For example, to shield the 40-m² radiator needed for a 30-kw, reactor-powered electrical turbogenerator (*17*), only 4 m² must be protected from penetration. If one operates the radiator in space for close to a year or 3.1×10^7 sec, the area-exposure time is $A\tau = 12.4 \times 10^7$ m²-sec. By imposing a 90% chance that no tube punctures will occur, one finds from Fig. 2 that an aluminum armor 0.66-cm thick gives ample protection. A shielding sheet of this size weighs 163 lb.

Uncertainties in calculation. The uncertainties in these calculations are introduced by possible errors in estimating the masses and densities of meteoroids in space. For example, if the mass of a zero-magnitude meteor is 1 gm, the armor thickness can be reduced by ~2.6. Also if the densities of the small meteoroids with masses from 2 to 20 mg are 0.05 gm/cm² and if the penetration of aluminum falls off as sharply with projectile density as penetration of copper does (*16*), the armor thickness may be reduced by a factor of ~10. If both these cases occur the meteoroid hazard practically disappears since ordinary tube thickness provides an adequate armor.

BIBLIOGRAPHY

1. M. G. Coombs, personal communication; M. G. Coombs. "A Design Procedure for a Minimum Weight Mercury Radiative Condenser," unpublished paper
2. M. A. Zipkin, E. Schnetzer. "Design Compromises in Space Power Systems," proceedings in publication (Tenth International Astronautical Congress, London, 1959)
3. F. L. Whipple. Photographic meteor orbits and their distribution in space, *Astron. J.* **59,** 201 (1954)
4. L. G. Jacchia. The physical theory of meteors, VIII, Fragmentation as cause of the faint-meteor anomaly. *Astrophys. J.* **121,** 521 (1955)
5. A. C. B. Lovell, "Meteor Astronomy" (Clarendon Press, London, 1954)
6. F. L. Whipple, personal communication
7. D. W. R. McKinley. Meteor velocities determined by radio observations, *Astron. J.* **113,** 225 (1951)
8. G. S. Hawkins. "A Radio Echo Survey of Sporadic Meteor Radiants, *Monthly Notices Roy. Astron. Soc.* **116,** 92 (1956)
9. G. S. Hawkins. Variation in the occurrence rate of meteors, *Astron. J.* **61,** 386 (1956)
10. L. A. Manning, V. R. Eshleman. Meteors in the Ionosphere, *Proc. of the IRE* **47,** 186 (1959)
11. F. L. Whipple in "Vistas in Astronautics (Pergamon Press, Los Angeles, 1958)
12. M. Dubin. "Meteoric Dust Measured from Explorer I," Air Force Cambridge Research Center (Cambridge, Mass., undated)
13. E. R. Manring. Micrometeorite measurements from 1958 alpha and gamma satellites, *Planetary and Space Sci.* **1,** 27 (1959)
14. F. L. Whipple, to be published in *Nature;* A. R. Hibbs, to be published in *J. Geophys. Research*
15. R. L. Bjork. "Effects of a Meteoriod Impact on Steel and Aluminum," paper P-1662 presented at the Tenth International Astronautical Congress (London, 1959)
16. J. L. Summers, A. C. Charters. High-speed impact of metal projectiles in targets of various materials, in "Proceedings of the Third Symposium on Hypervelocity Impact, F. Genevese, ed. (Armour Research Foundation of Illinois Institute of Technology, Chicago, Illinois, 1959)
17. M. G. Coombs, personal communication

Space Vacuum Poses Design Problems

By LEONARD D. JAFFE, *Jet Propulsion Laboratory, Pasadena, California*

THE EXTREME SPACE VACUUM presents two major problems to designers of space-vehicle hardware:

- First, the surfaces of materials exposed to the vacuum can sublimate or evaporate, especially at high temperatures. To counteract this effect designers must choose materials with low vapor pressure (see table).
- Second, surfaces in frictional contact tend to weld together when exposed to the very low vacuums of space. These surfaces have to be lubricated with a material that prevents welding, but will not itself evaporate into vacuum.

Evaporation and Sublimation

The rate at which molecules leave a surface in a vacuum is given by the Langmuir equation (*1–3*): $w = (P/17.14)(\sqrt{M/T})$ (W is rate of evaporation or sublimation in gm/cm²/sec; P is vapor pressure of material in mm Hg; M is molecular weight of material in gas phase; T is temperature in ° K.) Calculated results of metal evaporation are given in the table.

In spacecrafts one must consider the effects of vacuum on both the inorganic and organic materials in the surface. For inorganic compounds both evaporation and decomposition are important. One computes rates of decomposition to volatile products by substituting the equilibrium-decomposition pressure in the Langmuir equation.

On the other hand, since most of the organic materials used in spacecrafts are long-chain polymers, they go off into a vacuum not by evaporating, but by breaking down into smaller, more volatile fragments. Since the molecular weight of the fragments and the decomposition pressures of the polymers are not known, the Langmuir equation cannot be used to give decomposition. Instead, one must make experimental studies of polymer weight loss in vacuum. Results indicate that some polymers loose $>10\%$ of their weight each year at temperatures $\leq 200°$ F.

Reducing Friction in Vacuum

How friction can be reduced by lubrication may constitute one of the greatest problems for operating spacecrafts successfully in vacuum. On earth, surfaces absorb films of oxygen and water vapor; this "dirt" plays a major part in reducing friction. In a vacuum, however, since surfaces are clean and free from absorbing films of atmospheric gases, they commonly weld together on contact. Thus wear rates and friction coefficients become high (*4–6*).

The most promising way to preserve lubrication in a high vacuum is to reduce the exposure of the contact surfaces. For example, a seal around a joint gives maximum protection from the vacuum. Even a less perfect enclosure like a sealed bearing increases the life of a bearing.

Some low vapor-pressure oils and greases also protect surfaces from friction. Depending on their exact composition and molecular weight, commerical oils and greases of the same general type vary widely in vacuum performance. Silicone, petroleum and ester bases have successfully lubricated ball bearings at high speeds for 1,000–2,000 hr in vacuums of 10^{-5}–10^{-6} mm Hg (*7–9*).

In addition, coats of molybdenum disulfide (*10, 11*), and thin platings of silver (*12*), gold (*13*) or barium (*14*) lubricate satisfactorily for 1,000 hr. Tetrafluoroethylene in contact with itself or with steel is also a good lubricant at pressures of 10^{-6} mm Hg (*15*).

Testing in a Vacuum

The pressure in space at an altitude of 125 miles is $\sim 10^{-6}$ mm Hg; beyond 8,000 miles it is $< 10^{-12}$ mm Hg. For laboratory studies of sublimation and decomposition, however, it is unnecessary to test at such low pressures. If the laboratory pressure is $\leq 10^{-1}$ mm Hg, the mean-free path of vapor molecules is several meters. Thus collisions in the gas rarely occur and evaporated molecules or fragments can return to the test surface only by condensing on the vacuum-system walls and then resubliming. To prevent this the walls are colder then the specimen.

For lubrication and surface property studies, when space conditions are simulated, air molecules should be prevented from reaching the surfaces and building up layers of absorbed atmospheric gases. At 10^{-6} mm Hg, air molecules reach an exposed, clean surface so fast that a monomolecular air layer builds up in < 2 sec. At 10^{-9} mm Hg, however, the layer builds up in 25 min; this may be long enough to carry out friction experiments (*16*).

BIBLIOGRAPHY

1. I. Langmuir. Vapor pressure of metallic tungsten, *Phys. Rev.* **2,** 329 (1913)
2. F. H. Verhoek, A. L. Marshall. Vapor pressures and accommodation coefficients of four non-volatile compounds; Vapor pressure of Tri-m-cresyl phosphate over polyvinyl chloride plastics, *J. Am. Chem. Soc.* **61,** 2737 (1939)

Metal Evaporation in High Vacuum (*3*)

Element	*Temperature (° F) at which evaporation is:* 10^{-1} *cm/yr*	10^{-2} *cm/yr*	10^{-1} *cm/yr*
Cd	100	170	250
Se	120	180	240
Zn	160	260	350
Mg	260	350	460
Li	300	410	530
Pb	510	630	800
Ag	890	1,090	1,300
Sn	1,020	1,220	1,480
Al	1,020	1,260	1,490
Be	1,140	1,300	1,540
Cu	1,160	1,400	1,650
Au	1,220	1,480	1,750
Ge	1,220	1,480	1,750
Cr	1,380	1,600	1,840
Fe	1,420	1,650	1,920
Si	1,450	1,690	1,970
Ni	1,480	1,720	2,000
Ti	1,690	1,960	2,280
V	1,870	2,150	2,460
Pt	2,120	2,440	2,840
B	2,240	2,580	2,980
Zr	2,340	2,740	3,150
Mo	2,520	2,960	3,450
Ta	3,250	3,700	4,200
W	3,400	3,900	4,500

8. S. Dushman, "Scientific Foundations of Vacuum Technique," p. 18 (Wiley & Sons, Inc., New York, 1949)
4. F. P. Bowden, J. E. Young. Friction and adhesion of clean metals, *Nature* **164,** 1089 (1949)
5. F. P. Bowden, J. E. Young. Friction of clean metals and the influence of adsorbed films, *Proc. Roy. Soc. (London)* **A208,** 311 (1951)
6. G. W. Rowe. Vapor lubrication and the friction of clean surfaces, *Proc. Conf. on Lubrication and Wear,* 333 (Institution of Mechanical Engineers, London, 1957)
7. M. E. Freundlich, C. H. Hannah. Problems of lubrication in space, *Lubrication Eng.* preprint 60AM5B-1, (1960)
8. O. H. Lange, B. Steverding, L. Werner (Army Ballistic Missile Agency, 1960) unpublished work
9. F. J. Clauss, private communication
10. M. E. Bell, J. H. Findley. Molybdenite as a new lubricant, *Phys. Rev.* **59,** 922 (1941)
11. V. R. Johnson, G. W. Vaughn. Investigation of the mechanism of MoS_2 lubrication in vacuum, *J. Appl. Phys.* **27,** 1173 (1956)
12. T. H. Rogers, private communication
13. H. F. Villaume (New Hampshire Ball Bearings, Inc., 1959) unpublished work
14. Z. J. Atlee, J. T. Wilson, J. C. Filmer. Lubrication in vacuum by vaporized thin metallic films, *J. Appl. Phys.* **11,** 611 (1940)
15. R. F. King, D. Tabor. The effect of temperature on the mechanical properties and the friction of plastics, *Proc. Phys. Soc. (London)* **B66,** & 728 (1953)
16. G. F. Vanderschmidt, J. C. Simons, Jr. Material sublimation and surface effects in high vacuum, in "First Symposium, Surface Effects on Spacecraft Materials," p. 247, F. J. Clauss, ed. (Wiley & Sons, Inc., New York, 1960)

Thermal Control in Space Vehicles

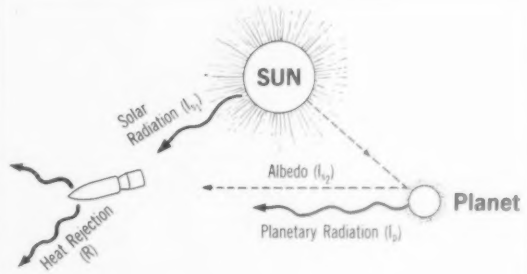
By THOMAS O. THOSTESEN and FRED N. WOLF, *Jet Propulsion Lab., Pasadena, California*

THE EXTREME HEAT-FLUX CHANGES that spacecraft encounter constitute a threat to payload instruments and living occupants. For example, a satellite passing into the earth's shadow receives fluxes that are ~10 times less than those in direct sunlight (see table). Therefore active or passive thermal-control methods must be used to keep interior temperatures within a prescribed range (*1*).

This range is set by the electronics and living creatures in the craft. For example, batteries do not operate properly below −5° or above 50° C (*2*). At temperatures >80° C they suffer permanent damage. The temperature range for men must be even smaller. In the Mercury capsule the normal temperature range will be 72–80° F; a peak temperature of 120–140° F will exist only during re-entry.

Thermal-Control Methods

The thermal-control problem in spacecraft involves predicting the heat fluxes a vehicle will encounter under all situations and then controlling against these fluxes.



What Affects Spacecraft Temperatures?

Time rate of change of temperature for a spacecraft is

$$\frac{dT}{dt} = \frac{I_s + I_p + Q + X - R}{mc}$$

The meaning of these symbols is given in the figure or below.

I_s = total solar thermal influx = $I_{s_1} + I_{s_2}$; Q = heat generated or removed in craft by heat sources or sinks. Includes heat from electrical components and phase change of materials; X = heat fluxes during prelaunching, launching and re-entry; mc = heat capacity.

Heat Fluxes on a 1-ft dia Spherical Satellite

Altitude (miles)	*Direct sunlight (Btu/hr)*	*Max. albedo (Btu/hr)*	*Terrestrial radiation (Btu/hr)*
1,580 (apogee)	348	79	34
223 (perigee)	348	187	74

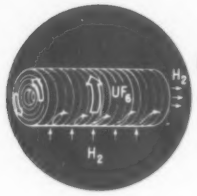
Control in satellites. In the past, weight and power restrictions on satellite payloads kept designers from regulating temperatures with active control systems. Instead they used passive techniques that involve choosing surface materials and coatings with good radiative properties, manipulating internal heat-paths and launching satellites at times favorable to minimizing thermal-flux variations. In addition, instruments are thermally isolated from the skin so that internal temperatures will not follow large surface-temperature excursions when the satellite passes through the earth's shadow.

Control in future spacecraft. As more powerful booster rockets are built, spacecraft will travel farther into space and encounter thermal-flux variations for longer periods of time. For example, near Mars at perihelion a 1-ft diameter vehicle receives 182 Btu/hr solar radiation; near Venus at perihelion the same craft receives 675 Btu/hr. In addition, reactor power sources will produce internal heating of other spacecraft components by radiation and by high reactor and power-cycle temperatures.

Passive control will still help to keep the temperature in equilibrium. In addition, active systems will give closer control of critical areas. By phase changing materials with high latent heats, intermittent or transient heating loads can be overcome. Heaters, heat pumps and coolers will satisfy long-term requirements.

BIBLIOGRAPHY

1. A. R. Hibbs. The temperature of an orbiting missile, Progress Report No. 20-294 (Jet Propulsion Laboratory, Pasadena, Calif., March 28, 1956)
2. A. R. Hibbs, E. P. Buwalda, T. O. Thostesen. Temperature control of the explorers and pioneers, in "First Symposium Surface Effects on Spacecraft Materials," F. J. Clauss, ed. (John Wiley & Sons, Inc., New York, 1960)



Advanced Concepts

SECTION V—*As a candidate to propel future-generation rockets, the gaseous-fuel reactor promises to outperform solid-fuel propulsion reactors by a factor of three. Vortex-flow or electromagnetic schemes appear as the most likely engineering solutions to the major problem of fuel-propellant separation.*

Along a different tack, propulsion by nuclear explosions (p. 100) points to the possibility of space ships literally the size of ocean-going freighters

Gaseous Propulsion Reactors

By ROBERT V. MEGHREBLIAN, *Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California*

We have recognized for some time that even though a nuclear rocket engine using solid fuel elements could achieve substantial gains in specific impulse over the best chemical engine (*1*), the performance would be limited ultimately by the maximum permissible temperature of the elements. Gaseous fuel systems would be free of this constraint but so long as solid-fuel systems themselves had yet to be demonstrated, such schemes have not received serious study. Now that progress has been made with solid-fuel systems, there is renewed interest in these more advanced nuclear engines.

Our purpose here is to outline the essential features of the gaseous systems and describe some of the current ideas of how the technical hurdles we can now foresee might be overcome. Our analysis will show that the performance of a gaseous-phase reactor is ultimately limited by the temperature of solid materials because the unavoidable absorption of gamma heating in the reactor structure eventually places a ceiling on gas-phase heating. Nevertheless, gaseous systems promise significant advances over present-day propulsion schemes. As a low-thrust interplanetary vehicle, a gaseous propulsion unit could deliver a given payload in shorter flight times than an ion propulsion system; as a high-acceleration (ground takeoff) rocket, the gaseous system could develop a specific impulse up to a factor of three greater than solid fueled nuclear systems.

The outstanding problem to be solved for these systems is the one of efficiently separating the fissionable gas from the propellant gas before the latter is expelled.

Performance Analysis

We will derive the ultimate performance of gaseous reactors by considering the performance, in quite general terms, of a reactor concept in which a region of the nuclear core is *non-temperature limited*. For a system thus released from the usual temperature constraints, it will be possible to exhibit the full capabilities of the nuclear rocket. Any number of practical reasons may arise to prevent this complete freedom; nevertheless, this approach will at least reveal the maximum gains that might be realized from the nuclear process (specifically gas-phase fission-heating) and in so doing provide a standard for evaluating each new propulsion system, whether direct nuclear or other.

To achieve the most general description of a nuclear rocket engine we combine the non-temperature-limited reactor concept with an engine complex such as shown in Fig. 1. This particular arrangement is not to be taken literally, since any number of other practical solutions could be considered, but the particular components and their characteristics as postulated here are essential to the argument. The figure shows the temperature-limited zone in a central location and the non-temperature-limited in a surrounding annular region. The former might be made up of solid fuel plates. We will refrain from any detailed description of the latter region, except to recognize that what is really meant by "non-temperature-limited" is that this region most likely contains fissionable material in the gaseous state. Several basic questions come to mind

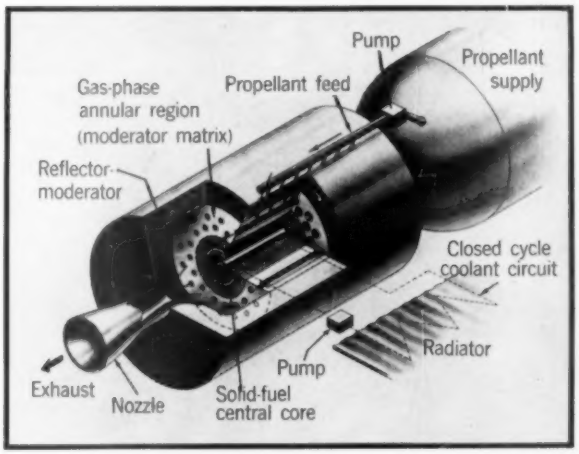


FIG. 1. CONCEPTUAL DESIGN of nuclear rocket reactor has two region core. Inner solid-fuel region is temperature limited by plate assemblies. Gaseous fuel in cylindrical passages of outer region has no temperature limit in and of itself

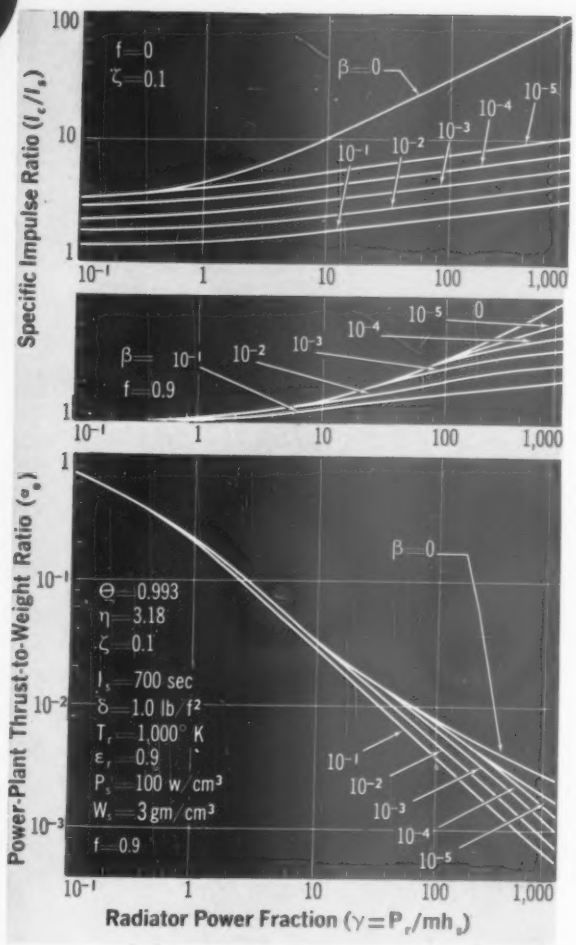


FIG. 2. SPECIFIC IMPULSE RATIO (above) versus fraction of power rejected to radiator for (a) all gaseous phase (f = 0) and (b) 10%-gaseous-phase, 90% solid-phase heating (f = 0.9)
FIG. 3. THRUST-TO-WEIGHT RATIO (below) for engine of Fig. 1 versus radiator power fraction and thermal radiation parameter β

about this nuclear rocket system:

- Does the performance of the system have an upper bound, i.e., is there a maximum possible specific impulse attainable?
- If there is an upper bound, what constraints does it impose and how do they enter into the problem?
- What is the performance capability of the compromised system?

Performance Limit

In the proposed system the propellant is heated from the storage condition (at say enthalpy per unit mass $h_0 = 0$) to the maximum allowable solid temperature T_s (or enthalpy h_s) by first passing through a portion of the solid (temperature-limited) regions of the reactor and then through the gaseous region to be further heated to temperature T_e (or enthalpy h_e); from the gaseous region it is finally expanded through a nozzle into the exhaust jet.

The total power P produced by fission is expended in part by heating and accelerating the propellant and in part, rejected by the radiator. Thus, if P_r is the latter, and $\dot{m}$ the propellant mass flow rate, then

$$P = \dot{m}h_e + P_r \qquad (1)$$

From this basic relation and the distribution of fission power between the solid and gaseous fuel regions, one can obtain (2) an expression for the specific impulse I_e corresponding to the maximum enthalpy gained by the gas in passing through the complete engine:

$$\left(\frac{I_e}{I_s}\right)^2 = \frac{1 + \gamma(1-f)(1-\zeta) - \beta\left[\left(\frac{I_e}{I_s}\right)^8 - 1\right]}{f + \zeta(1-f)} \qquad (2)$$

where the specific impulse at enthalpy h_i is $I_i = (\sqrt{2h_i}/g)$, and $\gamma \equiv P_r/\dot{m}h_s$ and $\beta \equiv \sigma\epsilon_e A_e T_e^4/\dot{m}h_s$. Here, σ is the Stephan-Boltzmann constant, ϵ_e the emissivity and A_e the surface area, respectively of the gas in the cavities, f is the fraction of fission power released in the solid fuel, and ζ is the fraction that appears as gamma radiation.

The solution to Eq. 2 gives the maximum specific impulse ratio attainable in any rocket engine, given the solid fission-fraction f, the thermal radiation parameter β, and the radiator power fraction γ. To understand this result imagine that the specific impulse I_s corresponds to the maximum attainable in an all solid-fuel (entirely temperature-limited) reactor. Then I_e/I_s gives the additional gain realized by incorporating some gas-phase fission-heating. As may be seen in Fig. 2, substantial improvement in specific impulse is possible with increased gas-phase heating.

The ultimate performance is determined by the parameter ζ. The importance of this constraint is best revealed by a limiting case: if no radiator is provided ($\gamma = 0$), the thermal radiation from the gas cavities is ignored ($\beta = 0$), and the reactor is all gas-phase ($f = 0$), then Eq. (2) reduces to $I_e/I_s = \zeta^{-1/2}$. A reasonable value for ζ is 0.1, which gives $I_e/I_s = 3.17$. If we take $I_s = 700$ sec (for hydrogen propellant this corresponds to a reactor solids temperature of about 2,000° K) then $I_e = 2{,}210$ sec. The ratio 3.17 is a limiting value to the specific impulse attainable in this system. It arises because some nuclear radiation always penetrates the gaseous region and deposits in the surrounding solid. Since, if there is no radiator, regenerative cooling by the propellant is the only means of removing this heat from the solid, the maximum allowable gain in enthalpy h_s acquired in passing through the solid effectively sets, through the quantity ζ the corresponding maximum enthalpy content h_e for the gas phase.

The only way to increase I_e/I_s beyond the value $\zeta^{-1/2}$ is to incorporate a cooling system for the solid regions which corresponds to $\gamma > 0$. Eq. 2 shows that with the addition of a suitably large heat-rejection circuit, the effective ζ can be made arbitrarily small and I_e/I_s arbitrarily large. However, for any given γ an increase in the thermal radiation parameter β reduces specific impulse.

Let us return to the two questions posed above. First, there is no upper bound in specific impulse of our proposed nuclear engine if an increasingly larger fraction of the radiation power is rejected. Second, there is a constraint only if no heat sink (other than regenerative cooling) is provided. Adding a radiator, however, imposes a weight penalty that markedly reduces the thrust-to-weight ratio.

Figure 3 shows how the engine thrust-to-weight ratio a_e varies with radiator size (i.e., γ) for the case $f = 0.9$. For these calculations the engine is idealized to consist simply of reactor and radiator to give

$$a_e = \frac{I_e/I_s}{\gamma\eta + \frac{1}{\theta}(1+\gamma)} \tag{3}$$

where $\eta \equiv c_s\delta/2\sigma\epsilon_r T_r^4$ and $\theta \equiv 2p_s/w_s c_s$. δ is the radiator weight per unit area, ϵ_r and T_r the radiator emissivity and temperature, p_s the power density in the solid regions of the reactor, and w_s the weight per unit volume of the reactor solid. The choice of the parameter p_s for describing the reactor size is a convenience. For a given power P_s and volume V_s of the reactor solid, the power density p_s will depend very much upon heat transfer characteristics of the radiator coolant and the structural characteristics of the solid fuel elements. Thus the selection of a representative value of p_s must be based upon experience and a detailed design study of the coolant circuit. Figure 4 shows the influence of p_s on the engine thrust-to-weight ratio.

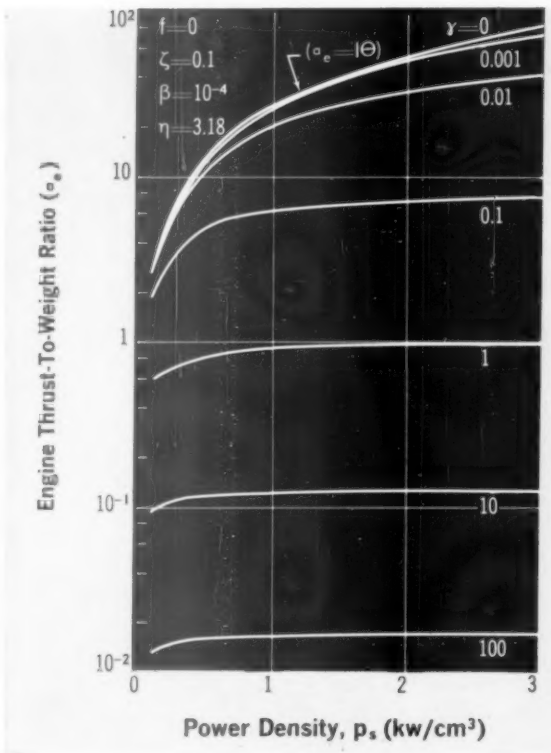
Propulsion Applications

Some measure of the performance of rocket vehicles propelled by fission reactors with gas-phase heating can be obtained from simple "burn-out velocity" calculations and trajectory analyses. In the general case for engine with radiator, the payload ratio in terms of the various vehicle component weights may be written:

$$\pi_{pl} \equiv \frac{W_{pl}}{W_o} = 1 - \frac{a\tau}{\theta I}(1+s) - \frac{a}{I}\left(\frac{1+\gamma}{\theta} + \gamma\eta\right) \tag{4}$$

where W_o is the initial total vehicle weight and consists of the payload, W_{pl}, the propellant W_p and tanks W_t, and the reactor W_n and radiator W_r. (Engine pumping circuit weight, reactor shield, etc. have been ignored for simplicity.) Here $I \equiv I_e/I_s$, $s = W_t/W_p$, a is the initial acceleration, and $\tau \equiv \theta t_p/I_s$ (with t_p the actual propulsion time.) Eq. 4 applies to the low-acceleration mission; for the high-acceleration mission, the radiator (η) term is omitted.

Consider first the low-acceleration mission. From Eq. 4 we can show the reactor and radiator weights increase at least proportionately with the specific impulse ratio, whereas the propellant weight varies inversely; thus for a given mission (i.e., velocity increment Δv) and initial acceleration, there will be an optimum specific impulse for achieving the maximum payload ratio (see Fig. 5). To find this maximum (*2*) we use the familiar equation $\Delta v = -c_e \ln(1 - W_p/W_o)$. Figure 5 shows the vehicle characteristics derived for an interplanetary mission requiring a total velocity increment $\Delta v = 66{,}500$ fps in the case of a 10,000-lb payload, and $I_s = 700$ sec.



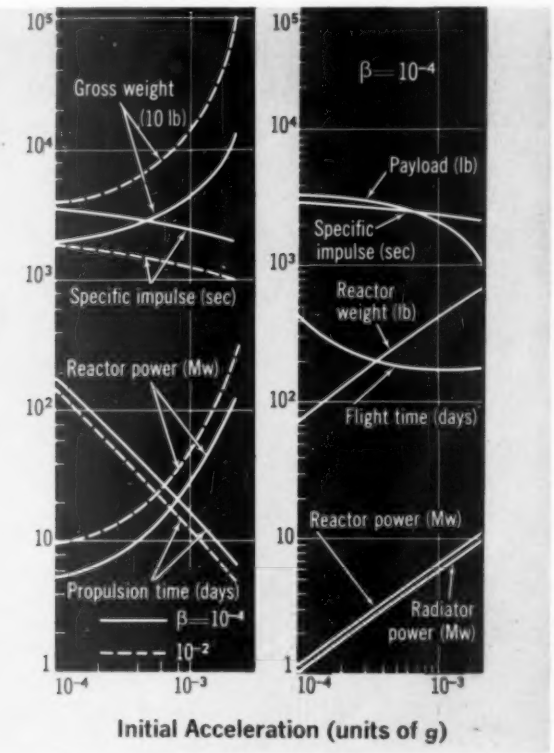


FIG. 4. THRUST-TO-WEIGHT RATIO (left) for rocket engine of Fig. 1 versus reactor power density for all gaseous-phase core

FIG. 5. VEHICLE PARAMETERS (a) optimized for gravity-free flight by method given in text for payload weight of 10,000 lb and (b) calculated by more detailed method for earth-orbit to Venus-orbit mission for vehicle gross weight = 10,000 lb. In both, $f = 0.9$, $\theta = 1$, $\eta = 3$, and $s = 0.05$. Venus vehicle would deliver 25% more payload than ion system in half the time

This elementary approach to performance analysis, although useful, is not entirely realistic. Therefore, an actual trajectory for an earth-to-Venus mission was also calculated for a gaseous reactor; the results are given in Fig. 5b. The mission consists of escape by spiral path from an earth satellite orbit at 400 mi to capture through a deceleration spiral into a 400-mi Venus satellite orbit. The vehicle gross weight at start of the acceleration spiral is 10,000 lb. For comparison, an ion-propelled spacecraft with a 0.6-Mw nuclear power plant could deliver a 2,700-lb payload in 433 days; the gaseous system flying the same trajectory could deliver 3,350 lb.

This example demonstrates the principal interest in gas-phase propulsion reactors for low-acceleration missions —namely, the prospect of high specific impulses (up to several thousand seconds) at high accelerations (exceeding 10^{-4} g). For low-acceleration missions this means quite high performance coupled with reasonable flight times (*2*).

In examining the high-acceleration missions we use again the Δv equation, but now add the gravity loss term $-gt_p$.

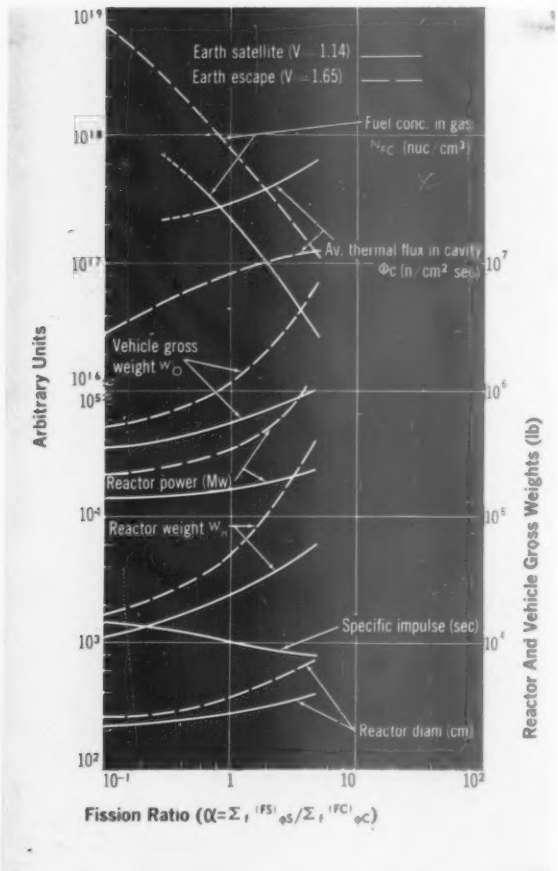

Earth satellite (V = 1.14)
Earth escape (V = 1.65)
Fuel conc. in gas N_{FC} (nuc/cm³)
Av. thermal flux in cavity Φ_C (n/cm² sec)
Vehicle gross weight W_O
Reactor power (Mw)
Reactor weight W_R
Specific impulse (sec)
Reactor diam (cm)
Arbitrary Units
Reactor And Vehicle Gross Weights (lb)
Fission Ratio ($\alpha = \Sigma_f^{(FS)}\phi_S/\Sigma_f^{(FC)}\phi_C$)

FIG. 6. VEHICLE PARAMETERS for high-thrust nuclear engine system as a function of fission rate in solid-fuel region divided by fission rate in gaseous-fuel region. Calculations assume payload of 100,000 lb and $\zeta = 0.1$, $a = 1.3$, $\theta = 20$, $x = 0.6$, $p_s = 2$ kw/cm³, $\sigma_a^{(FC)} = 1{,}000$ b and $\beta = 10^{-3}$

For these systems, there is no optimum specific impulse since the power plant weight (now consisting entirely of reactor and propellant) is inversely proportional to the specific impulse. The calculation is straight forward: given $V \equiv \Delta v/c_v$, the initial acceleration a, the specific impulse ratio I, and the payload weight to be delivered, the vehicle gross weight, engine thrust, reactor power, weight and size are immediately obtained. For the present purpose the reactor was taken to be a homogeneous, bare cylinder with height equal to diameter. The macroscopic absorption cross section Σ_a^{FC} corresponding to the critical concentration of the fuel in the cavity regions is

$$\Sigma_a^{FC} = \frac{\Sigma_a^M[(1-x)^2 + B^2L_M^2]}{(1-x)[S_F(1-x)+x]\{\eta' \exp[-B^2\tau_M(1-x)^{-2}] - 1\}} \quad (5)$$

where Σ_a^M is the macroscopic absorption cross section, L_M the thermal neutron diffusion length and τ_M the age-to-thermal of the moderator, x is the void fraction and η', the usual neutrons per absorption of the fuel. The symbol B^2 is the buckling, and $S_F \equiv \Sigma_a^{FS}/\Sigma_a^{FC}$, where (FS) denotes the solid fuel and (FC), that in the cavities.

Figure 6 shows the engine and vehicle characteristics (*3*) required to boost a 100,000-lb payload to an earth satellite orbit and to escape. The various parameters are plotted as a function of the parameter $\alpha \equiv \Sigma_f^{FS}\Phi_s/\Sigma_f^{FC}\Phi_c$, where Φ_s is the average thermal neutron flux in the solid region of the reactor, and Φ_c, that in the cavity. The calculations of the cavity fuel concentration N_{FC} assume $\Phi_S = \Phi_C$.

The parameter α in Fig. 6 is related to the solid-fission-fraction f by: $f = \alpha(1-x)/[\alpha(1-x)+x]$. Its importance may be appreciated from what it implies about the separation process. For example, if the separation factor is small (say $\ll 100{:}1$), then to keep the fuel loss rate within some fixed limit, the average concentration in the gas phase must be low, i.e., α must be large (see Fig. 6). Then the bulk of the fuel (required for criticality) must be carried in solid form, which means a large f and small specific impulse, and, therefore, small payload fraction and larger reactor weights and power.

Gas-Phase Separation

The importance of gas-phase separation of the fuel and propellant has been recognized for some time (*4*). Two basically different approaches have been suggested as possible separation mechanisms: the vortex method, based on the large difference in molecular weights of the fissionable species and suitable propellants, and the "magnetic-bottle" method, based on the fact that the fuel has a much smaller ionization potential than the propellant.

The vortex separation method requires a system of cylindrical cavities in the reactor core (*5*), each cavity containing a vortex flow field. The gaseous mixture of propellant and fissionable material is injected at the periphery of the tubes with a large ratio of tangential to radial velocity. Ideally, the mixture spirals into the center to be drawn off axially and discharged through one end. Under the enormous centripetal acceleration possible within such flows, the heavy fuel molecules experience an outward diffusion with respect to the lighter propellant.

Vortex flows can be generated hydrodynamically, by an

array of tangentially directed jets at the tube periphery, or magnetohydrodynamically, by externally imposed electric and magnetic fields. Theoretical analyses of the hydrodynamically induced vortex approach have been performed by several investigators (*5–7*). A detailed calculation (*5*) based on the assumption of an inviscid vortex which includes the volume heating by the fissionable species, indicates that rather high concentrations of fuel (10^{16}–10^{18} nuclei/cm^3) can be retained within the tube while considerably lower concentrations ($\sim 10^{14}$) appear in the vortex core and are lost in the propellant exhaust.

The realization of the vortex separation scheme awaits the production of a vortex flow with large tangential velocities but low radial mass flows. Preliminary experiments (*8–10*) have revealed a number of difficulties in obtaining suitable flows with even a single gas:

- The tangential velocity of a viscous gas does not follow the ideal inverse-radius law; the departure from the ideal increases with decreasing radial mass flow rates.
- The flow may be turbulent, giving rise to shear stresses many times greater than the viscous stresses.
- The tangential flow of the vortex results in a boundary layer at each end-wall of the vortex tube.
- At least at low Reynolds' numbers, axial velocities in the vortex core can be large compared to the local radial velocities.

Two sources are thought to be responsible for the turbulence in the flow: the turbulent boundary layer on the cylindrical walls and the tangentially directed inlet jets that produce the flow. This turbulence might prevent steep concentration gradients in the fuel distribution.

In spite of these complications, the experiments have produced a modest vortex (with maximum tangential Mach number of about 1.5) with fairly low radial flow rates and with turbulence levels of less than 1% (*10*). The separation experiments reported (*8, 9*) suggest some enrichment ($\sim$ a factor of two between maximum and vortex center) of the heavy species is possible, but the very large amounts required (at least 100 to 1) for the vortex reactor have yet to be demonstrated.

The idea of an MHD mechanism to drive the vortex has been suggested several times but (*11*), very little study has been devoted to the problem. The scheme sometimes proposed (but not yet analyzed) is a rotating magnetic field that would drive an ionized fissionable species in a vortex motion. An alternative scheme (*12–14*) is a radial electric field between a pair of cylindrical electrodes combined with an axial magnetic field. An ionized species contained within the cylindrical annulus would be subjected to a Lorentz force causing it to rotate. An idealized treatment of the hydrodynamic problem which includes the viscous forces (but does not include the separation phenomenon) has been reported recently (*13*). A sample calculation for a pair of infinite, concentric electrodes 100 and 10 cm in radii, with a magnetic field of 100 gauss, a total current of 10 amps/cm, an average viscosity of 7×10^{-4} gm/cm sec, and an average gas temperature of 2,400° K, indicates that a maximum tangential Mach number of about 8 can be achieved. The results of this preliminary analysis encourage further study.

Preliminary attempts to explore magnetic field containment of fissioning plasmas have been directed to cylindrical magnetic mirror configurations. The plasma of fissionable material is preferentially trapped in a central region by a magnetic field because of its relatively low ionization potential. The space around the plasma is occupied by the essentially neutral propellant gas. The fission energy is first deposited in the plasma by atomic collisions as the fission fragments slow down, and subsequently ejected by the plasma as thermal radiation, which is attenuated by the blanket of propellant.

The factors that determine the effectiveness of the scheme as a separation device include the particle density in the plasma, its temperature, the magnitude and the mirror ratio of the magnetic fields, and the nuclear requirements of the reactor. From an engineering point of view, the objective is to minimize the weight by having a high fuel (plasma) concentration and small cavity size. However, the propellant must be optically thick if it is to absorb the bulk of the fission energy; this means a large cavity. Also, for efficient magnetic confinement, the plasma density should be low.

Unfortunately the very simple configurations selected for the first analyses do not appear attractive because these various conflicting requirements lead to systems with slightly outlandish characteristics.

Estimates of confinement times with representative figures (*14, 15*) indicate that plasma leakage by radial diffusion across the magnetic field is not the crucial problem. The problem of axial confinement appears much more difficult. Estimates of the mirror loss rate indicate that the entire plasma would escape in milli seconds.

Apparantly the simplest scheme is not feasible. Perhaps the most promising course at this point would be to relax the requirement of high fuel density in the plasma and consider systems which carry additional fuel elsewhere in solid form, as in the vortex reactors discussed earlier.

BIBLIOGRAPHY

1. H. S. Tsien. "The Science and Engineering of Nuclear Power." vol. 2, p. 177 (Addison-Wesley Press, Inc., 1949)
2. R. V. Meghreblian, "Gaseous Fission Reactors for Spacecraft Propulsion," J. P. L. Technical Report 32–42, (July, 1960)
3. R. V. Meghreblian, "Gaseous Fission Reactors for Booster Propulsion," J. P. L. Technical Report 32-56, (March, 1961)
4. R. W. Bussard, R. DeLauer, "Nuclear Rocket Propulsion," p. 322 (McGraw-Hill Book Co., Inc., New York, 1958)
5. J. L. Kerrebrock, R. V. Meghreblian, "An Analysis of Vortex Tubes for Combined Gas-Phase Fission Heating and Separation of the Fissionable Material," ORNL-CF 57-11-3 (1957); J. L. Kerrebrock, R. V. Meghreblian. Vortex containment for the gaseous fission rocket, *J. Aero/Space Sci.* (in press)
6. J. Grey, "A Gaseous-Core Nuclear Rocket Utilizing Hydrodynamic Containment of Fissionable Material," preprint 848-59 (Am. Roc. Soc., San Diego, 1959)
7. R. G. Deissler, M. Perlmutter, "An Analysis of the Energy Separation in Laminar and Turbulent Compressible Vortex Flows" (Univ. of California, Berkeley, Calif., 1958)
8. J. J. Keyes, Jr., "An Experimental Study of Flow and Separation in Vortex Tubes with Application to Gaseous Fission Heating," paper presented at 15th meeting of Am. Roc. Soc. (Washington, D. C., December, 1960); J. J. Keyes, Jr., R. E. Dial, "An experimental study of vortex flow for application to gas-phase fission heating," ORNL-2837 (April, 1960)
9. R. G. Ragsdale, "Analysis and Experiment on an Air-Bromine Vortex System," NASA D-288 (1960)
10. J. M. Kendall, Jr., "Vortex Separation Experiments," J. P. L. Research Summary 36-3, vol. 1, part 2, p. 31 (California Institute of Tech., 1960); "Experimental Study of a Compressible Viscous Vortex with Applications to Gaseous Separation," J. P. L. Technical Release 34-168
11. J. Grey. Gaseous-core nuclear rockets, *J. Am. Rocket Society* **4**, 23 (1959)
12. G. V. Gordew, A. I. Gubanov. Acceleration of plasma in a magnetic field, *Soviet Phys. JETP* **3**, 1880 (1958)
13. C. S. Wu, "Transient Characteristics of a Rotating Plasma," J. P. L. Technical Release 34-122 (October, 1960)
14. S. T. Nelson, "The Plasma Core Reactor," GM 60-7630-2-9 Space Tech. Lab. (June, 1960)
15. H. Wahlquist, Research Summary 36-6, vol. 2 (Jet Propulsion Lab., Dec., 1960)

Thrust From Nuclear Explosions

By J. W. EERKENS,* *University of California, Berkeley, California*

THE ULTIMATE VEHICLE for space travel may be one propelled by the periodic explosion of small nuclear bombs (or bomblets). Such a scheme would make feasible gigantic space ships—in the same weight class as the NS *Savannah* (displacement weight = 11,000 tons) and with a similar "cargo" capacity (9,000 tons). With these space "liners" many people could travel in comparative comfort on long voyages taking with them complete laboratories.

Pulsed-thrust system studies have been the subject of two major projects—Project Orion, in being at General Atomics since 1958, and Martin's Nuclear-Bomb Pulsed Rocket studies. The table gives typical parameters for three different Martin models; parameters for the Orion vehicle are of the same order of magnitude.

The principle of operation of an Orion vehicle (see figure) is as follows: small nuclear bombs (~0.01 kiloton) are dropped at the rate of 0.1–1 per sec from the vehicle and exploded at distances of 100–1,000 ft. The bomb is loaded with propellant; when exploded it imparts its energy to this propellant (e.g., plastics or other low-molecular-weight materials). The energized propellant propagates from the explosion center to the vehicle where it hits a pusher plate that propels the vehicle. The pusher plate is made of ablative material (to absorb thermal and impact shocks) and is connected to the vehicle by water-cooled springs.

The Martin proposal† is similar in concept except that the explosion take place in a 130-ft dia spherical explosion chamber connected to a nozzle and water is injected into the chamber for propellant. In the Martin scheme, before starting the nuclear-bomb propulsion, the vehicle would first be boosted by a chemical rocket cluster to a 150-mile altitude at 8,000 ft/sec.

Alternatively the vehicle could be launched directly from the earth solely with bomb propulsion. Orion calculations conclude that contamination of the atmosphere for this kind of operation would be quite small. The first phase of propulsion to achieve orbit or escape would last only a few minutes during which occupants would experience a series of mild 2–3 *g* pushes. With its remaining supply of propulsion bomblets the space ship could roam around the solar system almost at will.

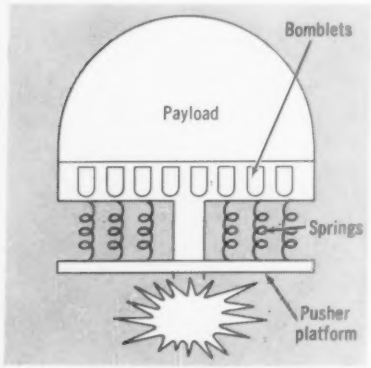
The feasibility of bomb propulsion has been checked out by "Project Put Put"—a 3-ft-dia 300-lb scale model of the Orion vehicle in which 3-lb high-explosive charges simulated the nuclear explosions. Because of the international moratorium on nuclear tests, no plans have been made for trials with nuclear charges. The total development costs for an operational Orion vehicle have been estimated at $1.5-billion.

Project Orion was given special attention earlier this year by an Ad Hoc Committee on Space headed by Jerome Wiesner, President Kennedy's special advisor on science (see p. 54). "Above all," the Committee said in discussing U. S. space policy, "we must encourage entirely new ideas which might lead to real breakthroughs. One such idea is the Orion proposal . . . This proposal should receive careful study with a realization of the international problems associated with such a venture."

Officials at Los Alamos, where the idea was born, said recently that Orion looks "very promising"; they asserted that a flight-test vehicle could be ready "in 5 years."

General Atomic's contract for Orion started in 1958 with an initial $2.5-million covering roughly the first two years of work; subsequently the project has received an additional $1.7-million covering roughly the present fiscal year.

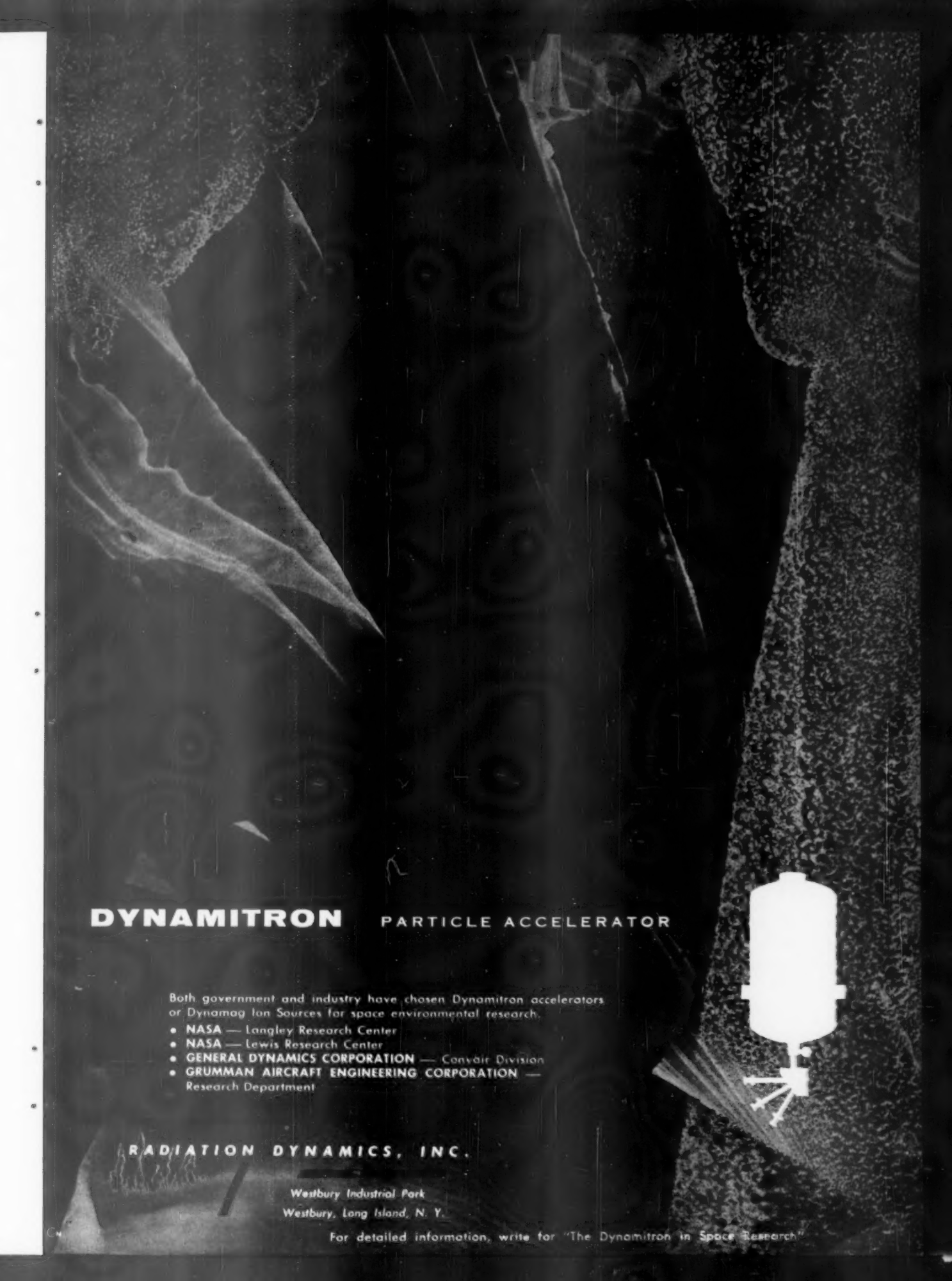
* PRESENT ADDRESS: Aerospace Corp., Los Angeles, California.
† *Aviation Week*, p. 34 (Jan. 25, '60).



ORION conceptual design has pusher plate made of ablative material to absorb shock of nuclear explosion. Plate transmits impulse to payload through water-cooled springs

Martin Nuclear-Bomb Propulsion Studies

Parameter	*Model:* I	II	IIA
Rocket chamber dia (ft)	130	130	282
Chamber-wall thickness (in.)	0.5	0.4	0.5
Rocket-chamber weight (lb)	1,000,000	200,000	2,000,000
Expellant (water) weight (lb)	2,060,000	3,240,000	32,400,000
Payload weight (lb)	350,000	2,920,000	29,200,000
Total vehicle weight (lb)	3,520,000	6,720,000	67,200,000
Total vehicle length (ft)	300	300	361
Energy per bomb (kt)	0.01	0.01	0.1
Explosion interval (sec)	1	1	1
Number of explosions	2,400	5,800	5,800
Water expelled per explosion (lb)	858	558	5,580
Average thrust (lb)	8,000,000	20,900,000	209,000,000
Specific impulse (sec)	1,150	1,150	1,150
Total velocity gain (fps)	26,000	26,000	26,000
Cost per bomb ($)	10,000–40,000	10,000	10,000


DYNAMITRON PARTICLE ACCELERATOR
Both government and industry have chosen Dynamitron accelerators or Dynamag Ion Sources for space environmental research.
• NASA — Langley Research Center
• NASA — Lewis Research Center
• GENERAL DYNAMICS CORPORATION — Convair Division
• GRUMMAN AIRCRAFT ENGINEERING CORPORATION — Research Department
RADIATION DYNAMICS, INC.
Westbury Industrial Park
Westbury, Long Island, N. Y.
For detailed information, write for "The Dynamitron in Space Research"

Rapid Flux Mapping in MTR Fuel Elements

By ROBERT STEINBERG, *Lewis Research Center, National Aeronautics and Space Administration, Cleveland, Ohio*

Rapid mapping of the neutron flux between plates of MTR-type fuel elements is possible with an instrument that we have recently designed and built for use with the 60-Mw Plum Brook Research Reactor now nearing completion at Sandusky, Ohio (*1*). With it one can completely survey the power density of a 22-fuel-element core such as that of Plum Brook in 10 hr or less while the reactor is operating at low power. Data are presented in a form immediately available for analysis.

Purpose

The Plum Brook Reactor is quite similar to the Materials Testing Reactor (MTR) and uses a standard 18-plate MTR fuel element. An important post-criticality test to be run at Plum Brook will be a survey of the power distribution.

Since core structural material limits access to the fuel elements and because fuel plates are closely spaced (0.1 in.), this type of measurement has in the past been accomplished by activation techniques. Wires are suspended in the water channels between fuel plates, and the flux at each point is then determined from the measured activity along the wire. This activation method usually requires from several weeks to months before the desired information is available, depending on the extent to which one can use automatic data-handling equipment (*2*). Objectionable aspects of this method are its static nature and the time and effort involved to position the wires initially and evaluate the information.

Instrument

As shown in Fig. 1, the instrument is 60 in. long, less than 3 in. in diameter, and houses 4 aluminum-clad solid-state fission probes which are simultaneously driven into the fuel element. Each probe is 50 in. in length with a rectangular cross section of 0.090 × 0.28 in. The detector consists of small silicon *p-n* junction wafers (Hoffman No. 58C) connected in series, each coated with U^{235}. The number of silicon wafers placed in series may vary from one to 20, depending on sensitivity and spatial resolution desired (*3*). Each detector to be used at Plum Brook will have five wafers in series and a thermal-neutron sensitivity of 0.5×10^{-3} count/n/cm². The corresponding spatial resolution will be 0.5 in., and useful life (variation in counting rate as function of radiation time <2%) will be 10^{12} nvt. The probe housing is constructed of aluminum and the two signal leads running the length of the probe, including the detector, are potted in paraffin.

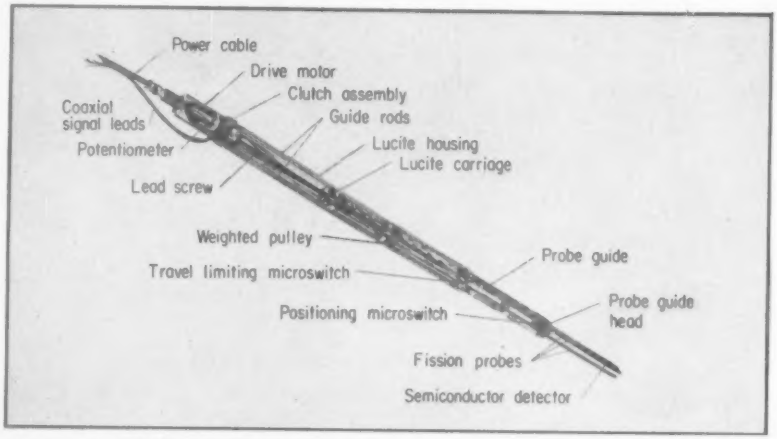


FIG. 1. INSTRUMENT is 60 in. long, <3 in. in diameter. Drive and sensor for vertical position are all contained in it and controlled from outside through cable

The probe guide has a special Lucite head containing a microswitch-actuated circuit that allows the instrument to be positioned from above on its own supporting power cable, even while the reactor is in operation. As a result no above-water positioning system is necessary; the motor drive can be packaged within the instrument. A potentiometer coupled to the motor drive is provided, with additional circuitry, to record the position of the probes. All measurements are made while the probes are in motion.

All four probes are mounted on a watertight Lucite carriage that rides on an aluminum drive screw and two stainless-steel guide rods. A pulley mechanism takes up the slack in the four coaxial signal cables as the probes are driven down between the fuel plates. This prevents the signal cables from becoming entangled in the control-rod mechanisms.

Underwater tests indicate that there

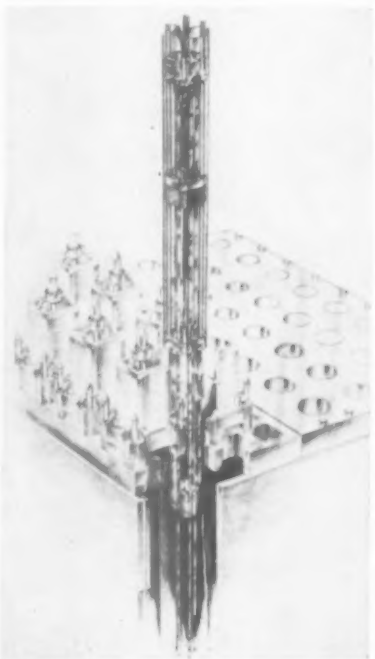
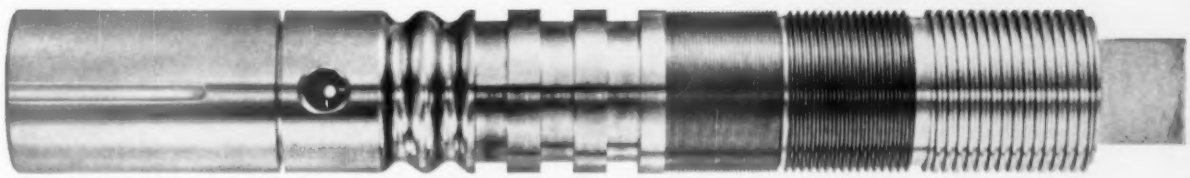


FIG. 2. IN REACTOR, compact assembly will not interfere with control rods

THEY LAUGHED WHEN WE SAT DOWN TO PLATE...

they didn't know about KANIGEN®



This shaft was turned. It was key-slotted, drilled, tapped and shouldered. It was threaded, milled, grooved and chamfered. It was step-bored, with three inside diameters. Who could plate a piece like this all over—inside and out—and expect a uniform coating?

Well, anyone who used KANIGEN® could expect it—and get it. In fact, we made this piece especially to prove it.

The KANIGEN® process for chemical nickel alloy plating produces a uniform thickness of coating, regardless of the contours of a part. This uniformity permits full machining operations prior to coating, with no subsequent cleanup.

KANIGEN® offers corrosion resistance equal or superior to that provided by wrought or electrolytic nickel.

For complete technical details write or call your nearest General American office. Ask for Kanigen Bulletin No. 258. You'll find that with plating as in so many other industrial areas, *it pays to plan with General American.*

Kanigen Division

GENERAL AMERICAN TRANSPORTATION CORPORATION

135 South LaSalle Street • Chicago 3, Illinois

Offices in principal cities

KANIGEN GENERAL AMERICAN TRADE MARK

TOP NUCLEAR MATERIALS

EUROPIUM OXIDE

SAMARIUM OXIDE

Available from

Vitro

right now!

HIGH BURNUP

MINIMUM DAMAGE

EFFECTIVE NEUTRON ABSORBER

STABILITY UNDER RADIATION

By tailoring to your individual requirements, substantial cost savings are possible.

Clip this ad and mail to Vitro today for:

☐ Technical data

☐ Further information on any aspect of rare earth technology

VITRO CHEMICAL COMPANY

A SUBSIDIARY OF VITRO CORPORATION OF AMERICA

342 MADISON AVENUE

NEW YORK 17, NEW YORK

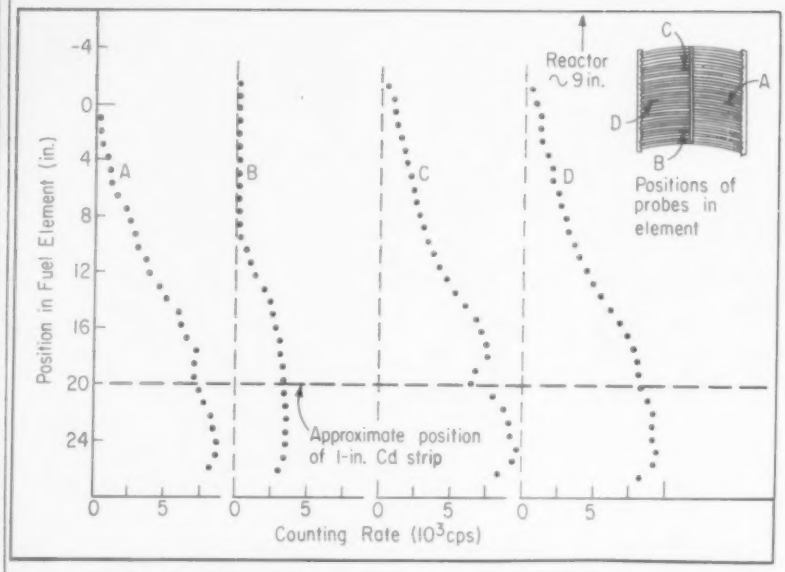


FIG. 3. SAMPLE RESULTS are from mapping flux in MTR-type element standing near Zero Power Reactor. Cadmium on side toward reactor disturbed flux at Probes A, C, D

are no leakage problems and that the instrument functions perfectly in its water environment. Experience has shown that it takes no longer than 60 sec to position the instrument on a fuel element.

Using It

Figure 2 shows the instrument in operating position in the Plum Brook core. The instrument head is shaped to pass between control rods and fits easily into the end box of the fuel element. During power mapping the Plum Brook Reactor will be run at ~3 watts. At this power no coolant flow is required and each detector will furnish a maximum of 15,000 cps, measurements being made every ½ in. It takes 7.2 min to map a fuel element, and during this time each of the four probes will supply 57 measurements over the 28.5 in. of travel. Measurements will be made as the probes are being withdrawn from the fuel element. Since the total worth ($\Delta k/k_{at}$) of all four probes when fully inserted in the core is less than 0.0004, the resultant flux perturbation is quite small. Only 3 hr of actual reactor running time is required to completely map the core. (This excludes the reactor down time spent in moving the instrument).

The associated readout system has a single counting channel which is used with a solenoid-actuated coaxial switch that cycles from probe to probe. Fission pulses are monitored on an oscilloscope, and a dual preset counter controls the counting channel. The data are immediately printed on paper tape recording the probe number, position in the fuel element and counting rate. An *x-y* point plotter provides a visual account of the power variation within a fuel element and makes the data immediately available for analysis upon completion of the traverse.

Results

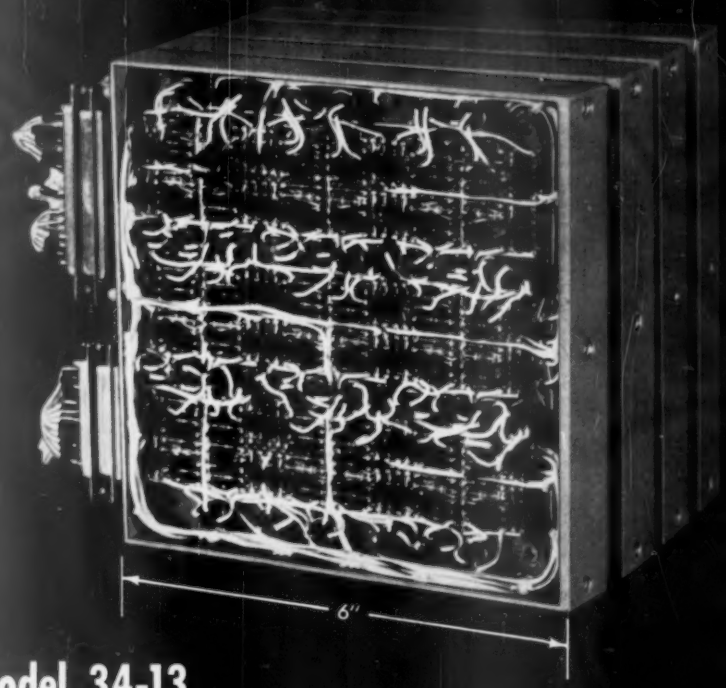
Figure 3 shows the results of vertical flux traverse of an MTR fuel element with a prototype of our power survey instrument that has a 1-in. spatial resolution. These data were obtained by placing an MTR fuel element and a section of the top grid plate in a water-filled, 5-in.-diameter Lucite cylinder ~9 in. from the NASA Zero Power Reactor. A strip of cadmium 1 in. wide was taped on the convex surface of the fuel element ~4 in. from the bottom of the fuel plates. Its effect can be seen on probes A, C and D. Probe B, being farthest from the reactor and several diffusion lengths in from the edge of the Lucite cylinder, shows the expected undisturbed distribution in flux. The complete traverse, including the time for the *x-y* plotter to produce Fig. 3, took 7 min.

Cost of building the instrument is ~$1,000. All other equipment is standard and readily available.

BIBLIOGRAPHY

1. R. Steinberg, Trans. Fifth Intern. Instruments and Measurements Conf. (Stockholm, 1960)
2. E. K. Relf, NUCLEONICS **15**, No. 4, 86 (1957)
3. R. Steinberg, *Trans. of ANS* **2**, 226 (1959)

for SATELLITE or SPACE PROBE



RIDL Model 34-13

32 channel pulse height analyzer and multiplex data handling system

The RIDL Model 34-13 is a special purpose *Pulse Height Analyzer* with time base *Multiplexing* storage and transmission ability. It may be used to measure and store low level signals from transducers linked with any type of sensing element or from any type of radiation equipment.

as analyzer

The Model 34-13 is a complete laboratory instrument, capable of analyzing pulses of varying amplitude – of storing data for short or extended periods of time — and of relaying information through either redundant or destructive readout through a telemetering system. Data is quickly cleared from the memory in preparation for a new cycle of analysis, storage, and readout.

as multiplexer

The Model 34-13 may be used as a piece of universal equipment, or multiplexer— starting with such information as that from human factors engineering systems, thermocouples, strain gauges, pressure gauges, power indicators and yaw indicators — and of recording, switching, or storing digitized information to be read out on program or command.

A major feature of the 34-13 is its fast transmittal time. Data may be read out two or three channels at a time, taking only the most and least significant data bits. Maximum and minimum limits may be set — *down* to 0.05 millivolts and *up* to 5 volts (the equivalent of 2 Mev particles).

Size: 5" x 6" x 6" **Power Consumption:** 1 watt
Weight: 5.1 lb. **Temperature Range:** —10°C to +55°C
Count Rate: 5 x 10^4/ sec. **Channel Width:** 1% of full scale
Shock and Vibration tested.

For full details write today for Model 34-13 brochure.

RIDL INC.

Radiation Instrument Development Laboratory, Inc.

61 EAST NORTH AVENUE • NORTHLAKE, ILLINOIS
PHONE: MUrray 1-2323 • Cable Address: RADILAB

Optical instrumentation for accurate measurement of remote or inaccessible objects

Gaertner M901 General-purpose Cathetometer

CATHETOMETERS

Gaertner Cathetometers are designed for accurate measurement of vertical distances or displacements. They are ideally suited for measuring where the object or action is remote or not accessible by ordinary means. Gaertner produces a wide variety of precision-constructed cathetometers to meet your individual requirements.

- **General-purpose Cathetometers**—These combine a high degree of accuracy with a maximum of convenience. Range 100 cm, focusing range 60 cm to infinity.
- **Precision Cathetometers**—For maximum accuracy and rigidity. Readings directly to 1 micron.
- **Micrometer Slide Cathetometers**—For precise measurement of short vertical distances. Range up to 4" or 100 mm. With telemicroscope, focusing range 12 cm to infinity.
- **Co-ordinate Cathetometers** — Permit making precise co-ordinate measurements on objects in a vertical plane. Focusing range 9" to infinity. Co-ordinate measuring range up to 24"x42".

SPECIAL PURPOSE PERISCOPES
REMOTE OPTICAL STRAIN MEASURING INSTRUMENTS

Write for Bulletin 162-56

The Gaertner Scientific Corporation

1257 Wrightwood Ave., Chicago 14, Ill.
Telephone: BUckingham 1-5335

Gas Chromatograph Monitors Reactor for Fuel Failures

By WILLIAM R. KRITZ
E. I. du Pont de Nemours and Company
Savannah River Laboratory, Aiken, South Carolina

Failures of the cladding on metallic-uranium fuel elements are signalled by release of radioactive fission products. The noble gases krypton and xenon are among the first of the radioisotopes to enter the coolant and provide convenient "rupture" signals for suitable monitors.

Significant amounts of radioactive gases are normally produced in the coolant by irradiation of dissolved air. These radioisotopes present a troublesome noise level for conventional activity monitors, and a large increase in noble-gas activity is usually required for reliable rupture detection.

The gas-chromatographic rupture monitor we have developed provides high signal-to-noise ratios by separating gases into relatively pure fractions, discarding the irradiated air and measuring traces of noble-gas fission products with beta-sensitive detectors. Prototypes of the monitor have given excellent service during two years of laboratory and field testing.

Monitor operation. Helium strips radioactive gases from the reactor coolant and is then dried and piped to a monitor. A sequence control (Fig. 1) actuates three-way solenoid valves to inject samples of the stripped gas into a chromatographic column at preset intervals. This column is a section of aluminum tubing (60 in. long, 0.25-in. o.d., 0.035-in. wall) packed with 20–50-mesh particles of Linde Molecular Sieve Type 5A and coiled to a 4-in. diameter spiral. The samples are eluted from the column with fresh helium and emerge through discriminator valves to a gas counting cell. The sequence control can be set to discard nitrogen and oxygen-argon fractions by timed operation of the discriminator valves.

The chromatographic scan (Fig. 2) shows a typical response of the instrument to a synthetic mixture of argon,

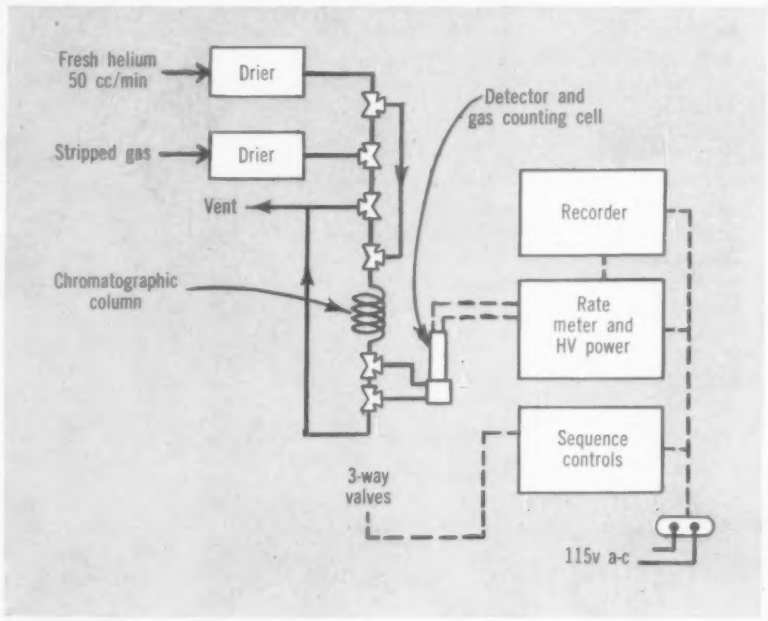
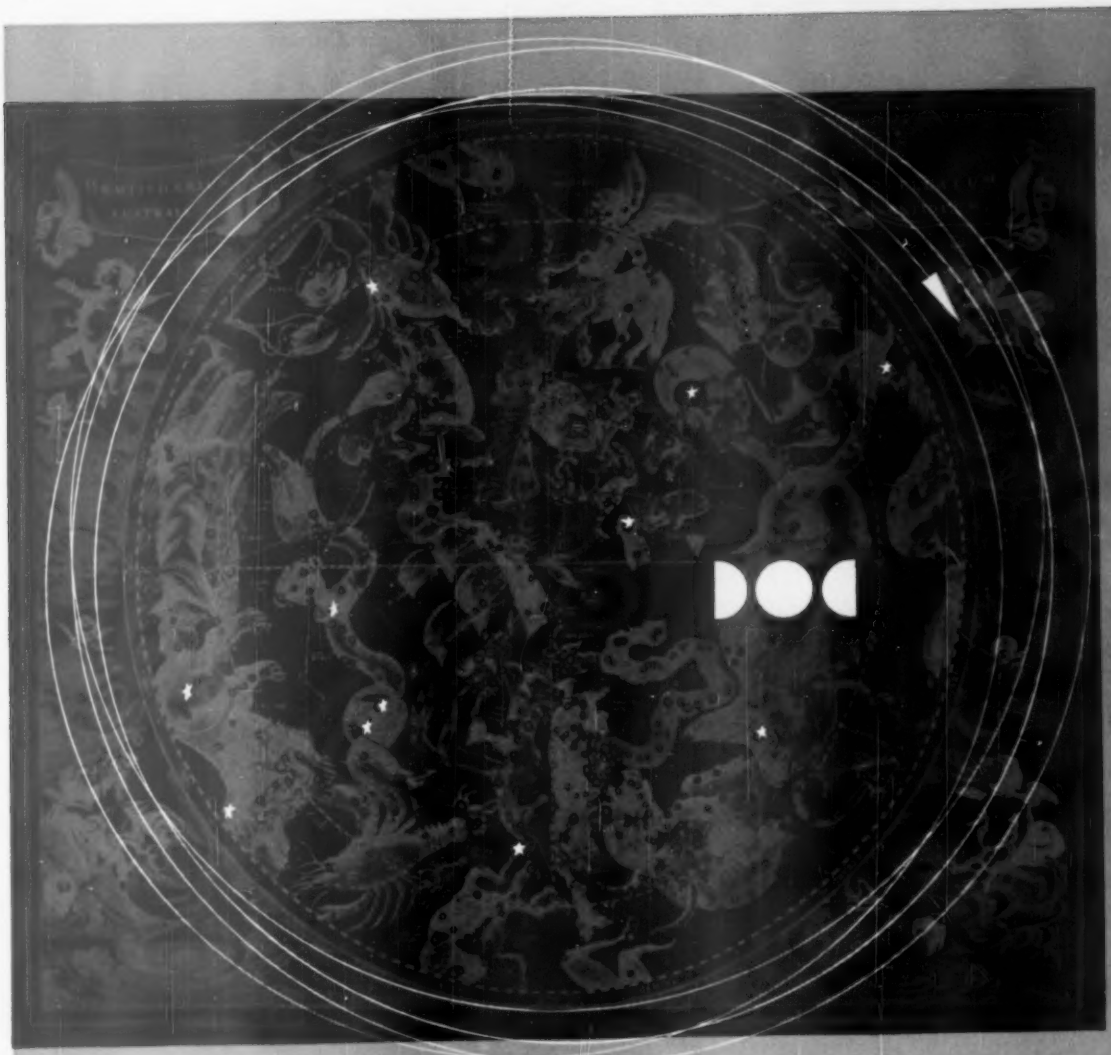


FIG. 1. GASES STRIPPED from coolant are separated in column



men at work on a new approach to the stars

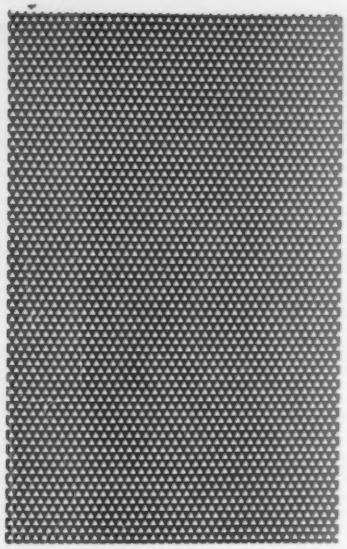
As principal instrumentation contractor for Project Rover, EG&G is already at grips with the central problems of nuclear propulsion for deep outer space exploration. A control, instrumentation and data acquisition system designed and operated by EG&G is of basic importance in the full-scale testing of Rover's KIWI prototype engines, designed by the Los Alamos Scientific Laboratory. The EG&G system is being effectively applied to the solution of problems of heat transfer, neutronics, fluid dynamics and general control.

EG&G instrumentation is also at work in the application of nuclear energy to industrial uses (Gnome) and in the international program for detection of nuclear explosions (Vela). In oceanography, EG&G equipment is probing the ultimate ocean depths.

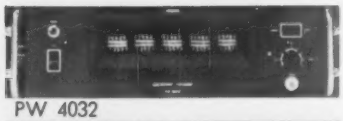
If you are interested in doing truly significant work with a vigorous, young organization of recognized professional stature, send your confidential resume to:
Lars-Erik Wiberg, 168 Brookline Avenue, Boston 15, Mass.
For a copy of "EG&G CAPABILITIES",
write Dept. MDA, at the same address.

EDGERTON, GERMESHAUSEN & GRIER, INC.

175 BROOKLINE AVENUE, BOSTON 15, MASSACHUSETTS • TEL. COPLEY 7-9700 • CABLE: EGGINC, BOSTON; TWX: BS 1080
WESTERN OPERATIONS: P.O. BOX 1912, LAS VEGAS, NEV. — SANTA BARBARA AIRPORT, P.O. BOX 98, GOLETA, CALIF



Scaler for direct connection of scintillation detectors or G.M.-counters



PW 4032

PW 4022

COUNTING CAPACITY: 5 decimal scaling stages; two binary prescalers. Total indicated counts: 400 000.
RESOLVING TIME: 0.5 μsec (first binary scaler).
INPUT SENSITIVITY: G.M.-counters: 0.5 V_{p-p}. Scintillation detectors: via built-in amplifier with adjustable attenuator: 5 mV_{p-p}.
H.V. RANGE: 300 - 2500 V in steps of 22 V.

Linear count rate meter for direct connection of G.M.-counters, scintillation- or proportional detectors

PW 4042

PW 4022

MEASURING RANGES: 300 - 1000 - 3000 - 10 000 - 30 000 c.p.m.
ACCURACY: 2 % of full scale.
TIME CONSTANT: 0.1 - 1 - 3 - 10 - 30 - 100 sec.
INPUT SENSITIVITY: G.M.-counters: 0.5 V_{p-p}. Scintillation detectors: via built-in amplifier with adjustable attenuator: 5 mV_{p-p}.
RECORDING: socket for connection of a strip chart recorder provided, resulting in an improvement of the accuracy to 0.5%.

PHILIPS

PHILIPS
nuclear equipment

N.V. PHILIPS' GLOEILAMPENFABRIEKEN - EINDHOVEN - HOLLAND

Particle accelerators - Reactor control instrumentation - Health protection and monitoring equipment - Radiation measuring and detection equipment - Geiger-Müller counters - Photomultipliers - Radio-active isotopes.

Gas Chromatograph

This article starts on page 106

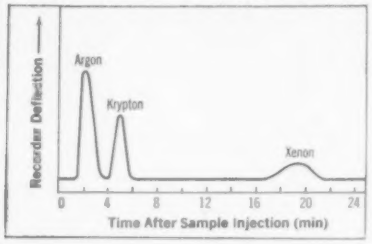


FIG. 2. TYPICAL SCAN of automatic chromatograph without discriminator

krypton and xenon radioisotopes, without discriminator action. Laboratory measurements show monitor sensitivity to be 4 μc/liter to 10.4-yr krypton-85 diluted in helium. Sensitivity could probably be improved by using larger sample aliquots or optimizing the detector system. The monitor components are stock items, with the exception of the automatic chromatograph. The recorder is a Brown Electronik, 0–25 mv range, with 1-in./min and 2-in./hr chart drives. An NRD model 560 counting-rate meter with integral high-voltage power supply, internal standardization and adjustable zero is a convenient integrating device. The detector is a thin (1-mm) anthracene crystal, optically coupled to a standard photomultiplier tube and preamplifier assembly, which faces a window of 0.002-in. stainless steel in the gas counting cell.

The chromatograph was assembled from standard components on an aluminum chassis and includes six Skinner three-way solenoid valves (V5D11220), two delay relays (115N010 and 115NC30), one Multilab timer assembly (10-min cycle with three SPDT switches), and one Melatron pressure switch, all wired conventionally.

With the counting-rate meter and a 1-0-10 chart, it is possible to set the recorder on zero with any reasonable background radiation and to read the chromatograph peaks directly as a deflection from zero. The adjustable zero also facilitates inclusion of a self-monitoring alarm system to warn of any malfunction.

* * *

This article is based on work performed under contract AT(07-2)-1 with the U. S. Atomic Energy Commission.

BIBLIOGRAPHY

1. W. R. Krits, DP-356 (1959)
2. W. R. Krits. GC rupture monitor—model 2 design (to be published as a DP report)

...4...3...2...1...LAUNCH!

As the atom moves into space, Ex-Cell-O Atomics will be there. For over forty years, Ex-Cell-O has been an important source of precision aircraft and missile products. ■ Look to Ex-Cell-O Atomics for advanced reactor controls and components, guidance system details, ultra precision parts and assemblies, remote handling equipment. ■ Ex-Cell-O Atomics' staff of design, development and production specialists are ready to meet your requirements. Write direct, or phone TOwnsend 8-3900; cable XLO; TWX DE 175.

Ex-Cell-O Atomics

EX-CELL-O
CORPORATION
DETROIT 32, MICHIGAN

61-12A

EX-CELL-O FOR PRECISION (XLO)

Scattering Shields for Space Power

By CARL N. KLAHR, *Technical Research Group, Inc., Syosset, New York*

Shielding the payload of a nuclear-powered space vehicle can be accomplished with a shadow shield designed to scatter radiation into space. Since there is no atmosphere around the vehicle to provide backscattering, it is quite as good to deflect the radiation into space as to absorb it. One feature of a scattering shield is multiple splitting of the shield into individual disks. This is effective when the buildup is large and no substantial geometric penalties are involved. As a second step one shapes the individual disk segments to increase their effectiveness. As a final step one places the remaining shielding material in the best positions available, reducing to a minimum the likelihood that radiation intercepted by the shield will be deflected back into the payload rather than scattered away from it.

There are important differences between this shielding problem and shielding on the earth and in the air. Weight reduction takes on unusual importance. Depending on the mission, the saving of 1 lb in a chemically launched vehicle corresponds to a gross weight saving of 60–500 lb (initially nuclear-powered vehicles will probably be launched chemically—see page 58). Because of difficulties of heat dissipation, heating effects of radiation are also unusually important. Configurations, too, may be quite different from those in use elsewhere; rockets may be long and thin or short and thick, depending on their propulsion schemes and missions.

Shield Optimization

One can compare any actual shield with an ideal one that uses the same material in the best way possible. To make an ideal shield one chooses materials with the largest removal cross section and assumes that every interaction removes a particle or photon and all its descendants from the field. Thus for a point source and a disk detector the attenuation of an ideal shield is $A = e^{-\sigma l}$, where σ is total cross section and l is the height of a conical shield with a spherical sector base.

In an actual shield the attenuation is less for four reasons: buildup of multiply scattered radiation, interception (scattering from shield to detector of radiation that would otherwise escape), nonoptimal choice and distribution of materials, and production of secondary gamma photons by neutron absorption.

Buildup. One can hope to eliminate the multiply scattered buildup contribution by splitting the shield into many disks so that scattered radiation goes into space rather than to the detector. The general idea is shown in Fig. 1.

With some simplifying assumptions one can calculate that if all neutrons and photons scattered by a disk contribute to buildup, the fraction of the radiation scattered from one disk and hitting the next one is as follows:

$$f(x) = 1 + \frac{x^2}{2} - \left[\left(1 + \frac{x^2}{2}\right)^2 - 1\right]^{1/2}$$

(x is distance between disks measured in units of disk radius). In terms of this function geometric attenuation caused by splitting the shield into n identical disks is

$$\alpha(D, n) = \left[f\left(\frac{D}{n+1}\right)\right]^{n+1}$$

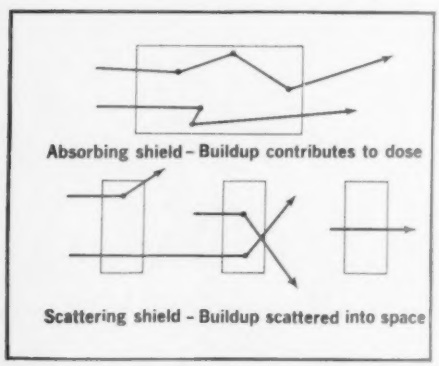
(D is source-detector distance). To compare split and unsplit shields it is convenient to define an improvement factor for the buildup radiation

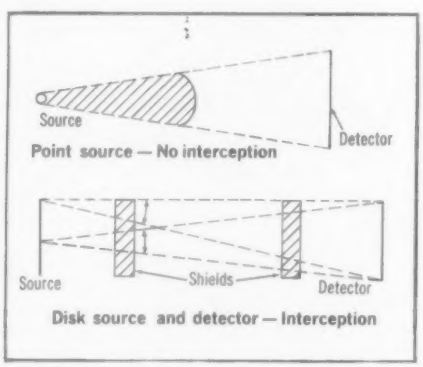
$$I(D, n) = \frac{\alpha(D, 1)}{\alpha(D, n)}$$

If one tabulates I as a function of D and n, inspection shows that substantial improvement is obtained for large D and n.

Although this improvement factor applies only to the scattered radiation, there are situations in which scattered radiation contributes most of the exposure. For example, for neutrons in heavy nuclides the buildup factor over 15 mean free paths may be several thousand. But neutrons in hydrogen and gamma rays exhibit much smaller buildups.

Interception. The shield itself may often intercept radiation that would otherwise escape. Consequently re-





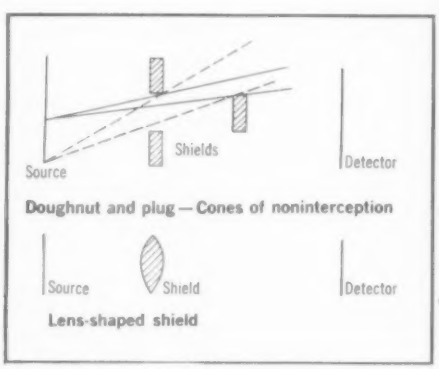


FIG. 1. SHIELD SPLITTING substitutes scattering to space for absorption; FIG. 2. INTERCEPTION scatters to detector radiation that would otherwise escape; FIG. 3. BEST ARRANGEMENT of material may greatly reduce shield weight

Here Is Your Guide
TO THE SERVICES OF A
Complete Nuclear Fuel Facility

	Cladding Materials Al Nb SS Be Zr	Pellets in Tubing SS Zr Al	Fuel and Fuel Alloys U-Zr U-Nb U-Al U-Mo U,Th	Fuel Dispersions and Ceramics UC UO_2-SS U_3O_8-Al UO_2 in graphite ThO_2 in graphite	Control Materials B-Al B-SS B_4C-Zr Hf
PRODUCTS					
Castings	√		√		
Clad Materials	√		√	√	√
Control Rods					√
Dispersions				√	√
Fabricated Assemblies	√	√	√	√	√
Fabricated Shapes	√		√	√	√
Foil	√		√		√
Fuel Elements	√	√	√	√	
Fuel Rods		√	√	√	
Poison Strips					√
Tubing	√				
Wire	√		√	√	
PRODUCTION SERVICES					
Annealing and Heat Treating	√		√		√
Assembly	√	√	√	√	√
Brazing	√	√	√		
Casting	√		√		
Cladding	√	√	√		√
Chemical Milling	√		√		√
Extrusion	√		√		
Machining	√	√	√	√	√
Materials Research	√	√	√	√	√
Rolling	√		√	√	√
Vapor Blasting	√		√	√	√
Welding	√	√	√		√
TESTING SERVICES					
Autoclaving	√	√	√	√	√
Chemical Analysis	√	√	√	√	√
Isotopic Analysis			√	√	
Metallography	√	√	√	√	√
Non-Destructive Testing	√	√	√	√	√

A CHECK LIST OF PRODUCT, SERVICE AND TESTING CAPABILITIES OFFERED BY M & C NUCLEAR PRODUCTS.

Our wide experience in the nuclear field, our skilled technicians and our specialized equipment enable us to suggest many worthwhile economies during the early stages of project planning. For our complete FACILITIES BROCHURE, "FUELS OF THE FUTURE", write to M&C NUCLEAR PRODUCTS.

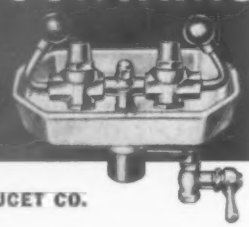
METALS & CONTROLS INC.
P. O. BOX 898 • ATTLEBORO, MASS., U. S. A.
A CORPORATE DIVISION OF
TEXAS INSTRUMENTS
INCORPORATED

IN EMERGENCY... contaminated eyes are instantly cleansed of dangerous particles and chemicals by *controlled* water streams from HAWS Emergency Eye-Wash Fountains. This "split second safety" before medical aid arrives can mean the difference between temporary eye irritation and permanent eye injury! HAWS will provide emergency facilities best suited for your safety program—minimizing hazards, reducing claims, lowering insurance costs. Get the facts by writing today for illustrated literature!

HAWS EYE-WASH FOUNTAINS

MODEL 7100
(old model 8930)

Basic eye-wash model with enameled iron bowl; quick-opening valve for manual operation; adaptable to treadle operation; chrome plated brass water pressure regulators and twin fountain heads. Wall mounted and pedestal models available.



HAWS DRINKING FAUCET CO.
Since 1909
1443 FOURTH STREET
BERKELEY 10, CALIFORNIA

EXPORT DEPARTMENT: 19 Columbus Avenue, San Francisco 11, California, U.S.A.

ALUMINUM NUCLEAR STORAGE RACK

by CPC

Engineered, machined and fabricated all aluminum nuclear spent fuel element storage rack designed by Stone and Webster, Boston, Mass. for Yankee Atomic Plant, Rowe, Mass.

QUALIFIED WELDERS

A.S.M.E. - National Boards
Aircraft - MIL-T-5021A
Navy - STD-248A
Code inspection by Mutual Boiler and Machinery Insurance Company

WRITE FOR ALUMINUM BROADSIDE

CPC engineering

STURBRIDGE, MASS.

Scattering Shields

This article starts on page 110

positioning a portion of a shield may produce a decrease in radiation dose rate to the payload. As shown in Fig. 2, a conical shield between a point source and a disk detector intercepts no radiation that would miss the detector in the absence of a shield. With a disk source and disk detector, on the other hand, any shield must intercept radiation that would otherwise escape.

If interception is large, appropriate shield geometries will reduce it. A doughnut-and-plug arrangement (Fig. 3) has holes in the shield to reduce interception and plugs beyond them to increase attenuation.

Best arrangement. If one can put shielding material where it is most effective, one may improve a shield design considerably. For example, the lens-shaped disk of Fig. 3 has most of the shield where most of the radiation passes.

As another example, a single disk has a best position between source and detector. Placing the disk near the source usually results in a lower dose than placing it near the detector because the most penetrating, unscattered radiation is incident at a larger angle to the normal to the surface. One has a new problem if the disk is split. Moving material away from the center increases the first-scatter dose and decreases the multiple-scatter dose.

Secondary radiation. Even if multiple splitting yields no significant benefits in reducing primary neutron or gamma dose, it may pay its way by reducing secondary gamma production. For example, in hydrogenous shields, which produce 2.3-Mev photons by neutron capture in hydrogen, splitting the shield tends to eliminate neutrons by scattering them into space before they slow to thermal energies.

Heat reduction. An important application of the multiply split scattering shield may be reducing shield heating by primary and secondary gamma photons. Even if multiple splitting does not significantly reduce the dose at the detector, it may be useful in this heat reduction. A factor of 50% in shield heating may mean the difference between being able to use a particular material and not using it. A scattering shield will also reduce neutron absorption and the resulting heating from secondary particles.

* * *

This work was supported by NASA.

General Atomic's Laboratory
San Diego, California

Challenging programs and opportunities in the development and design of advanced nuclear systems have been opened up through the founding of General Atomic Europe by General Dynamics Corporation and its General Atomic Division.

General Atomic Europe is a European company, staffed principally by Europeans and affiliated with General Atomic USA. A beneficial relationship is assured with the programs of advanced science and technology underway at General Atomic's John Jay Hopkins Laboratory for Pure and Applied Science in San Diego, California — the world's largest privately-owned center of diversified nuclear research and development.

Among the major programs of General Atomic is the High Temperature Gas-cooled Reactor (HTGR) encompassing the design and development of plants in sizes ranging from 40 MW to 500 MW.

General Atomic Europe, through its complimentary relationship with General Atomic USA and with the mutual objective of creating the most advanced nuclear products, has undertaken a program which emphasizes development of HTGR systems in the 100-200 MW range.

A few select openings exist in the programs of General Atomic Europe for scientific and technical talent with nuclear experience in heat transfer, gas flow and pressure vessel design, and for those with experience in conventional steam power plant design.

Please address inquiries to: General Atomic Europe, Weinbergstrasse 109, Zurich 6, Switzerland.

GENERAL ATOMIC EUROPE *A Member of the General Dynamics Group*

MILAN ZURICH DUSSELDORF

Fast-Reactor Safety Studies in TREAT—A Status Report

By C. E. DICKERMAN, E. S. SOWA and D. OKRENT
Argonne National Laboratory, Argonne, Illinois

The major uncertainties of safety of metallic-fueled fast reactors are related to core meltdown (*1*). To study this phenomenon, Argonne National Laboratory has been submitting fuel specimens to overheating conditions in a pulsed, thermal test reactor, TREAT (the Transient Reactor Test Facility), at the National Reactor Testing Station in Idaho (*2–5*).

The goals of the TREAT program are (1) to study the behavior of metallic fast-reactor fuel elements in the simplest possible configuration under various conditions of overheating, up to and beyond melting; (2) to "proof-test" mockups of actual metallic-fuel subassemblies or sections; and (3) to extend the studies of overheating to other fuels, e.g., oxides and carbides.

TREAT Design Facilities

The core-averaged, integrated thermal-neutron flux of TREAT for a transient initiated at 30° C and producing a maximum reactor temperature of 400° C is $\sim 3.8 \times 10^{15}$—more than twice the integrated flux needed to melt a natural-uranium sample initially at room temperature. In addition to bursts terminated by the change in neutron temperature, having a period of 40 msec or greater and a width at half-power of more than 140 msec, special control-rod drives provide "flat-top" transients, approximating a constant-power pulse of 1–30 sec duration.

The normal test hole is the shape of a single fuel element, 10.02 cm square. One or more horizontal slots, 55.9 × 8.89 cm, enable photographic viewing of the test section. Since TREAT is a thermal reactor, natural or low-enrichment uranium samples are used to avoid self-shielding problems.

Specimen capsules. The simplest TREAT experiments involve a single fuel element in a dry, opaque capsule (graphite-crucible support in a helium atmosphere inside a stainless-steel can). Thermocouples and post-test examination provide the test information. The graphite walls constitute a heat sink for "freezing" the meltdown products expelled from the specimens.

To enable high-speed photography of fuel behavior, a relatively large windowed container slides into one of the horizontal reactor slots. The sample is about 38 cm from the closest window to avoid bond-sodium deposition on the window when EBR-2 type elements are used.

A third capsule type, a modification of the dry, opaque capsule, permits study of specimen meltdown in stagnant sodium. Inside the graphite liner is an assembly consisting of a second stainless steel tube which contains the sample in its sodium bath and electrical heaters for preheating the sample and sodium before initiation of the transient.

Sodium loops. Later steps in the studies will cover single elements and element clusters in flowing sodium. A single-element sodium loop is being designed to fit within a special TREAT fuel element, allowing installation and removal from the reactor using standard fuel-handling techniques. Figure 1 shows a larger loop to be installed as a semipermanent structure in TREAT for meltdown of element clusters.

Instrumentation. Instrumentation development has centered around thermocouples, pressure transducers, optical cameras and an ultrasonic device which may provide average sample temperatures and should indicate when a break in sample continuity occurs.

Thermocouples have been welded to the outer cladding of dry samples, while development effort has centered on installing a tantalum-molybdenum couple directly in the uranium of a sample immersed in sodium (*7*). The optical-camera system uses a special xenon lamp source and high-purity fused-silica windows, which have shown no darkening or glow problems in preliminary tests.

Postirradiation examination. Following the exposure of specimens in TREAT, the capsule or loop is shipped to the hot-laboratory facility at ANL for examination.

For previously unirradiated samples, the procedure is quite simple since operations can be performed manually

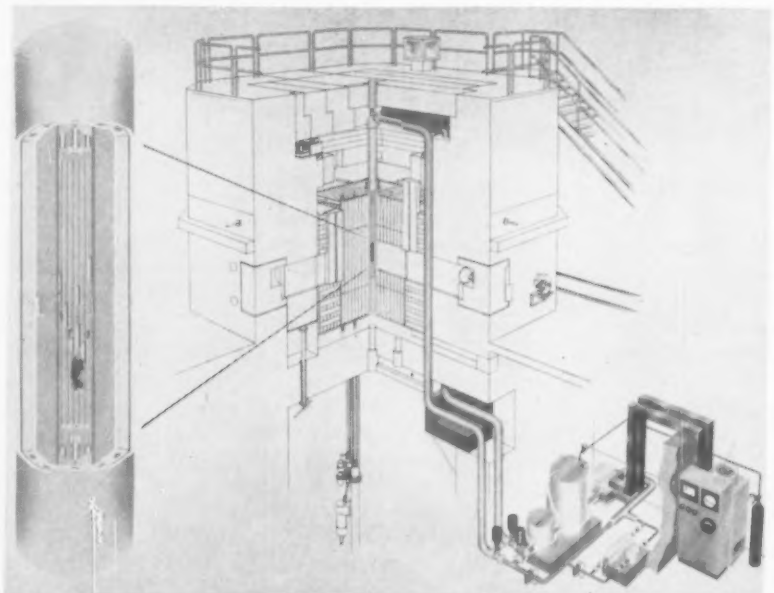
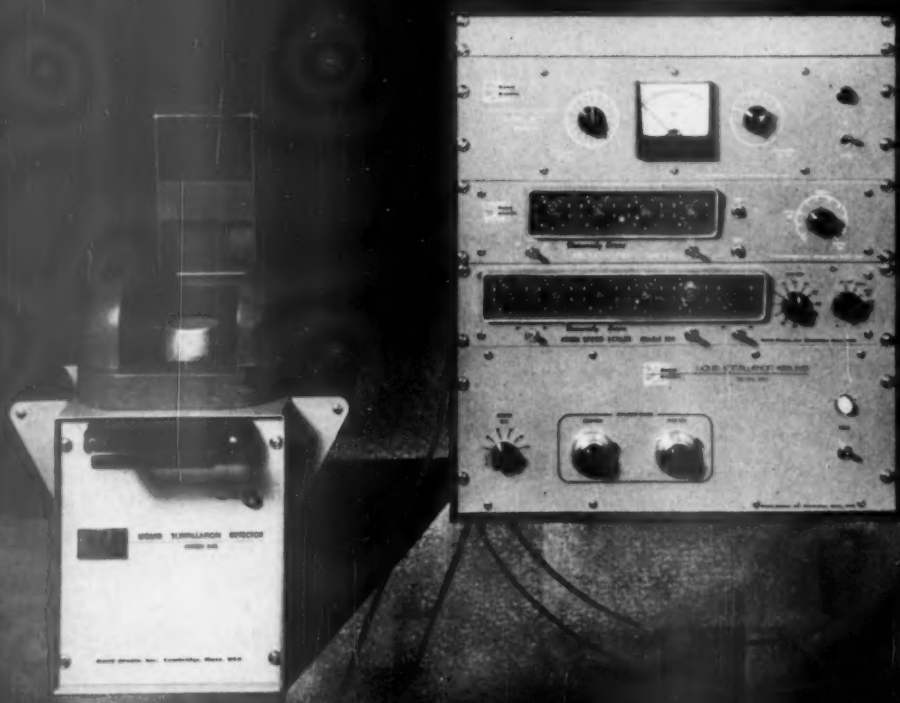


FIG. 1. LARGE SODIUM LOOP for testing fuel elements in TREAT. Sodium is from storage and surge tank in basement, along one leg (with partial diversion through cold trap and plugging indicator) to top of reactor, down through outer annulus of test section to bottom of section, upward through center specimen chamber of section. Return flow is through return leg to small settling tank finally to surge tank. Settling tank retains particulate uranium carried over during meltdown. Entire loop will be behind shielding and remotely operated. Test section will be removable for sample removal

Baird-Atomic pioneers LOW COST liquid scintillation



The development, field test, and customer acceptance of a versatile radioisotope manual liquid scintillation counting assembly has been completed. Here is a system for Carbon 14 and Tritium that incorporates simplicity and flexibility – that is in the price range of all laboratories.

Among its field proven features: simplified circuitry which assures reliable operation, negligible field maintenance; the high voltage supply, scaler and timer are all standard B/A instruments – they can be used with other systems and tailored to your special needs; specially designed, dark preadaption sample holder accepts a variety of sample configurations and sizes; the system is compact and versatile.

These – and other features of the Model 745 Liquid Scintillation unit – are available at the lowest cost you would expect to pay for reliable performance with liquid scintillation. You owe it to your budget to get more information – write or call your nearest B/A representative today.

Sales and service offices in: Cambridge, New York, Philadelphia, Pittsburgh, Cleveland, Washington, D. C., Atlanta, Dallas, Chicago, Los Angeles, San Francisco, Ottawa, Canada.

BAIRD-ATOMIC, INC.

33 university road · cambridge 38, mass.

in a glove box. On the other hand, preirradiated specimens will require remote-cave disassembly. Although a six-month "cooling-off" period is planned before their use in TREAT to permit fission-product decay, the fuel activity will still be high compared to the activity induced in TREAT.

The pyrophoricity of the resultant mixture of finely divided uranium in a sodium matrix will preclude the exposure of such samples to air. Thus, disassembly will have to be performed in an inert atmosphere.

Status of Program

TREAT attained criticality in February 1959. The first meltdown experiments were conducted in September 1959. Most experiments thus far have been on single fuel elements exposed to an axially uniform neutron flux in inert gas inside opaque capsules. Sample cladding temperature, and bond sodium release data where applicable, were combined with the results of postmortem inspections to determine types of sample failure and the associated temperature thresholds and to suggest the failure mechanisms.

As of March 1, 1961, 85 meltdown specimens have been irradiated in TREAT and given postirradiation examinations. These include 55 stainless-steel-clad EBR-2 Mark 1 specimens, 10 EBR-2 Mark 1 elements clad with the refractory metals tantalum and niobium, 18 shortened Fermi 1 elements and 2 stainless-steel-clad EBR-2 Mark 1 elements in stagnant sodium. An additional 6 steel-clad EBR-2 samples, 5 run in dry opaque containers and 1 in stagnant sodium, have been exposed in TREAT but not yet examined.

Irradiation conditions included constant power pulses, shaped axial neutron fluxes with an axial power generation profile typical of that for fast reactors, and short power pulses with total energy releases greatly in excess of that necessary to produce sample failure.

Unless noted otherwise, the samples described in the following discussion were subjected to a short (~0.2–0.5 sec) TREAT power burst. Because of the large heat sink afforded by the graphite meltdown crucibles, cooling rates of intact samples are relatively rapid. A sample heated to 1,000° C cooled about 300° C in ~20 sec.

EBR-2-Type Samples

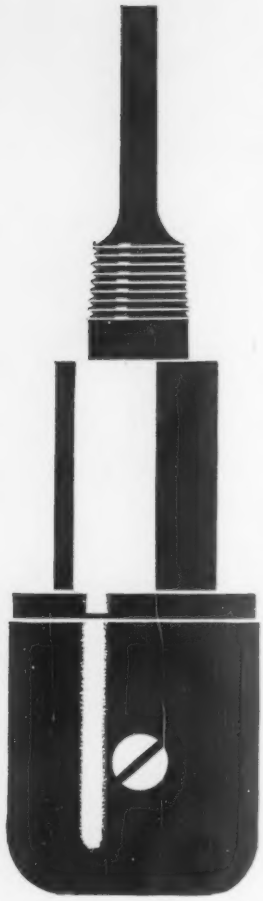
The first results on EBR-2 Mark 1, stainless-clad, uranium-alloy fuel elements and their testing in TREAT were described earlier by Sowa (*6*). The results can be described briefly:

1. Maximum cladding temperature up to 950° C. Elements retained integrity; sodium-bond voids and small patches of U-Fe alloy on fuel surface were seen. Fuel-element helical spacer wires increased damage severity by causing warping and enforced fuel-to-cladding contact.

2. 950–1,015° C maximum cladding temperature. Incipient or mild failures, cladding dissolution and expulsion of bond sodium to gas-expansion space above uranium. In cases of cladding penetration, gravity plus low sodium vapor pressure caused nonviolent escape of uranium alloy at the base of the element.

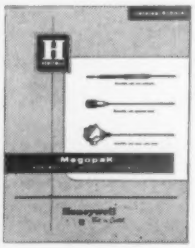
3. >1,015° C. Rapid failure and violent fuel expulsion and spraying against crucible walls because of high sodium vapor pressure.

Examination of samples subjected to constant power transients showed that there is no significant lowering of the temperature threshold of failure for exposure times up to 25 sec, although qualitatively there appears to be evidence for somewhat less severe failure. No appreciable difference in post-experiment condition was noted for these specimens between elements with helical spacer wires and those without. Only one sample given an axially shaped power profile has been examined. It recorded a maximum cladding temperature of 850° C and was undamaged. Five more elements have been run under similar conditions but not yet examined. Studies were made on the effects of short power bursts with a total energy input up to 250% greater than that necessary for failure. For these high energy inputs, the fuel alloy was found to be sprayed out laterally, relatively uniformly along the entire length of the element, and very little cladding remained. Three samples have been run in stagnant sodium capsules, and two of them have been given post-mortem inspections. One element, which received an energy input estimated to be sufficient to reach the approximate region of the failure threshold, did not suffer a cladding failure but did show a limited amount of fuel-cladding interaction upon removal of



MegopaK
THERMOCOUPLES

Honeywell's new line of hard-pack, small-diameter, mineral-insulated thermocouples. Available as bulk material (combination of wires, insulation and sheath); elements (with measuring junction); and as complete assemblies (with terminations and mounting attachments). From this one dependable source come thousands of other accessories to make your instruments perform at their very best.



Get details from your Honeywell field engineer, or write today for Catalog G100-4.

MINNEAPOLIS-HONEYWELL, Wayne and Windrim Avenues, Philadelphia 44, Pa. In Canada, Honeywell Controls, Ltd., Toronto 17, Ontario.

Honeywell
First in Control
SINCE 1885

a new shape for power...

● Fuel for the Liquid Fluidized Bed Reactor, under development at Martin for the AEC, is in the form of loose pellets of low-enriched uranium dioxide. Experiments now under way, including critical tests, may prove LFBR holds some of the answers to the problem of lowering costs in nuclear power production. A fresh, solid idea . . . being developed by imaginative, but down-to-earth engineers.

Nuclear powerplants, isotopic power, advanced reactor systems, propulsion systems, nuclear components . . . In these and other fields, the FUTURE is TODAY at Martin-Nuclear!

. . . And in our rapidly expanding programs we have significant opportunities for ENGINEERS and SPECIALISTS at various levels of experience for work involving design, analysis, development and experimentation in advanced nuclear applications.

You will enjoy the *way of work* at Martin-Nuclear, where the exceptional engineer is assured exceptional advancement. You will enjoy the *way of life* in Maryland, the beautiful land of cultural advantages, outdoor sports, the Colts, the Orioles, fabulous seafood and ideal family living.

WRITE
giving brief outline of your education and experience to

MR. J. W. PERRY
Director of Executive Staffing, Dept. 50-A

NUCLEAR DIVISION

MARTIN
BALTIMORE 3, MD.

Where control depends on measurement!
CON-O-PAK THERMOCOUPLES
FROM -300°F TO 4000° PLUS
The world's finest thermocouples. New process increases precision and temperature range. Exceeds all military and commercial specs. Con-O-Pak is used in aircraft, missiles, nucleonics, chemical processing. Useful data? . . . Ask for "The Con-O-Pak Story."
CON-O-PAK
CONTINENTAL SENSING INC.
1950 N. Ruby St., Melrose Park, Illinois

FLEXIBLE AND SHEATHED THERMOCOUPLES • THERMOCOUPLE WIRE • HEATING ELEMENTS • CONNECTORS

NEW! ELECTRONIC CONTROL METER

Patent Nos. 2,871,450 and 2,967,278

MODEL 2547

WITHOUT ELECTRICAL CONTACTS provides continuous output signal past selected control setting, with uninterrupted, accurate full-scale indication at all times. No electrical contacts at control point, so no control-point problems. No undesirable feedback because indicating and transistorized switching circuits are completely isolated. No pull-in or locking coils or special power supplies required. Available in two standard models with single or double independent control-arm circuits. Both may be had with scales for horizontal or vertical mounting, with zero at center, left or right.

FOR ACCURATE INDICATION AND CONTROL IN:

Communications • Missile Checkout • Nucleonics • Signal Monitoring • Voltage Control • Process Control • Data Processing • Alarm Systems • . . . or wherever dependable, fail-safe control is required

WRITE FOR ENGINEERING DATA SHEETS on our complete line of panel meters, side indicators, Electronic Control Meters, miniature multitesters.

miniaturization headquarters
international instruments inc.
P.O. Box 2954, New Haven 15, Conn., Cable: "INTERINST"

Fast Reactor Safety

This article starts on page 114

the cladding. The other specimen, given an energy input ~30% greater disintegrated, and its appearance was consistent with that of the dry elements which underwent extensive failure.

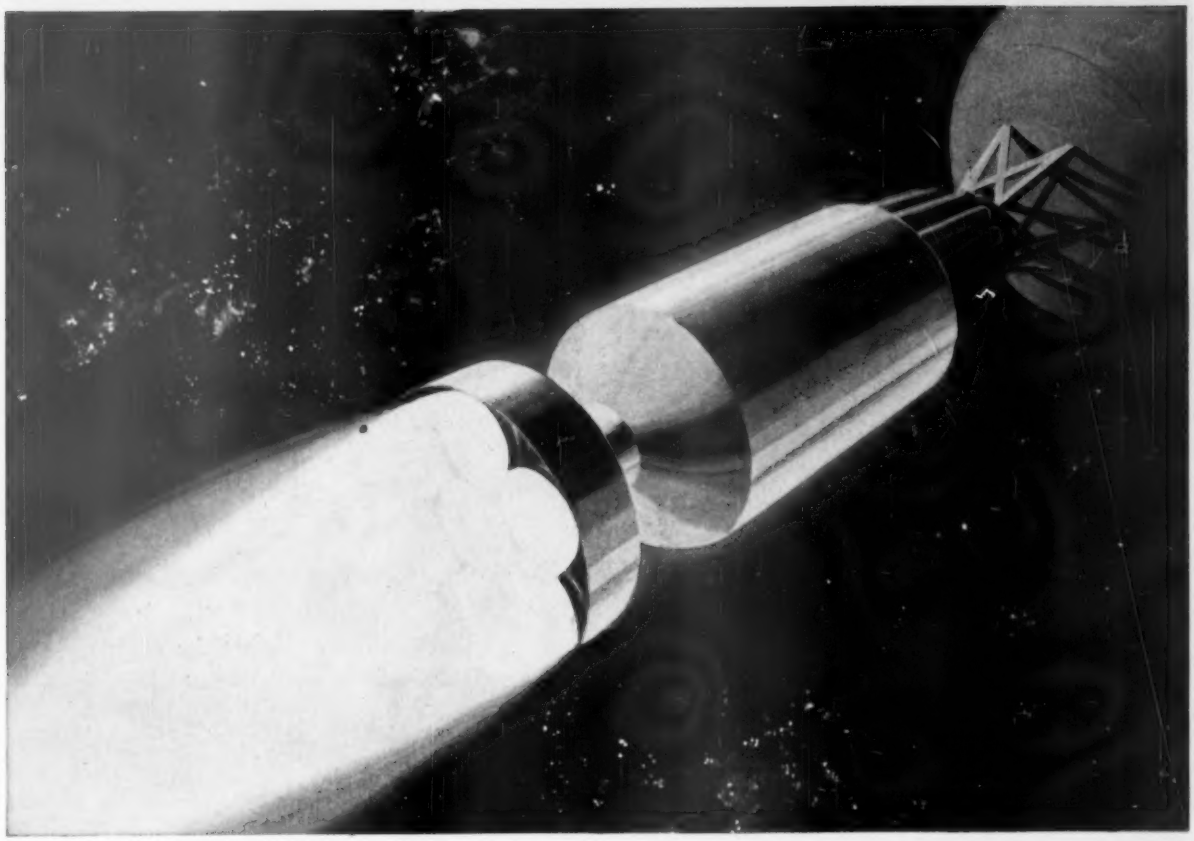
The TREAT results with EBR-2 elements demonstrated the need for in-pile experiments to simulate core conditions. Earlier out-of-pile experiments led to failures of a highly localized nature and gave no indication of the more extensive failures and liquid fuel alloy movement under the influence of sodium pressure observed in TREAT samples.

Results on refractory-metal-clad EBR-2 elements were an interesting variation on those from the Mark 1 samples. The former could be heated ~150° C or more above the melting range of the uranium alloy for short times without failure. Failure occurred at localized flaws, with vigorous expulsion of essentially all the fuel alloy.

Data on the time required for molten uranium to penetrate a 0.51-mm-thick cladding metal (*8*) and relationships of time-of-penetration with cladding thickness (*9*) and with temperature (*8*) have been published. Application of these data to a simple model indicates that cladding failure from internal pressure due to the bond sodium should

FIG. 2. EXTENSIVE FAILURE of Fermi-1 fuel pins raised to high cladding temperature during short power bursts

NUCLEAR ROCKET PROPULSION AT AEROJET-GENERAL



Nuclear rockets, with a performance capability nearly twice that of the highest-specific-impulse chemical rockets, have been of major interest to Aerojet-General for several years.

Exploratory studies were initiated by Aerojet in 1955 to ascertain the feasibility of nuclear rockets, and the technical advances required to develop a successful nuclear propulsion system were determined. This work at Aerojet has undergone continuous expansion under government and company sponsored programs. Included are: preliminary design of engines and vehicles, simulated nuclear engine tests, radiation hazards research, analog computer system design (to simulate nuclear rocket operation), nuclear test facility construction, and the design, development, testing, and manufacture of reactors.

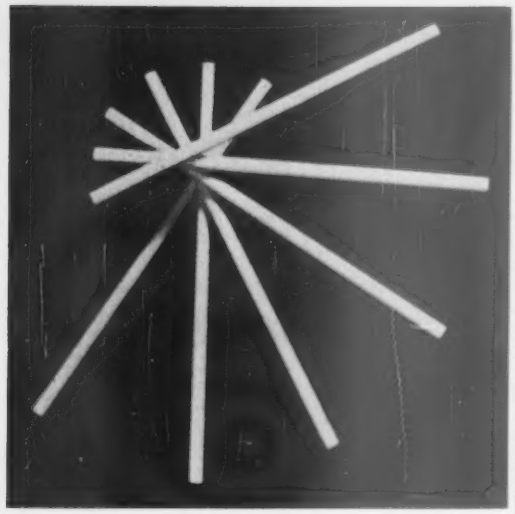
These programs have resulted in significant progress toward the development of a practical and reliable nuclear propulsion system. They are based on Aerojet's combined experience in liquid and solid propellant rocketry, nuclear technology, and cryogenics—experience which ensures that the challenge of a new era in propulsion can, and will, be met.

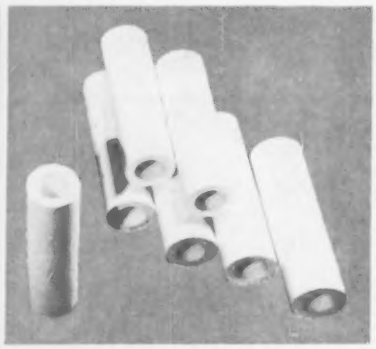
Aerojet-General®
CORPORATION

THE GENERAL TIRE

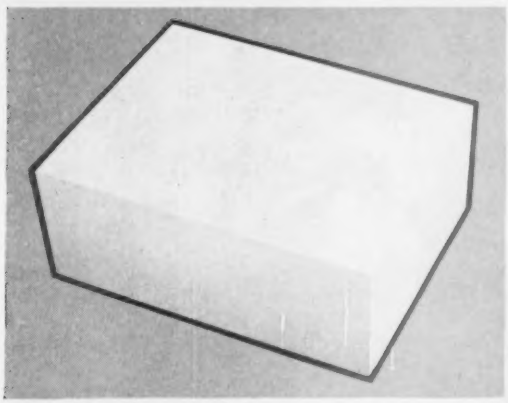
A SUBSIDIARY OF THE
GENERAL TIRE AND RUBBER COMPANY

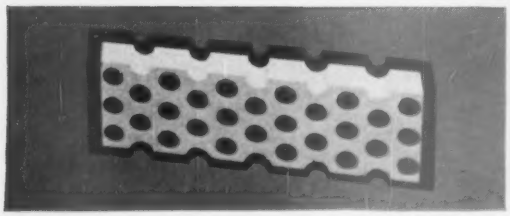
THE SHAPES OF NUCLEAR PROGRESS....

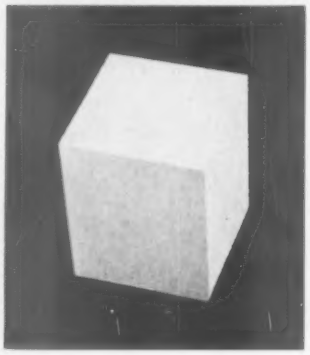


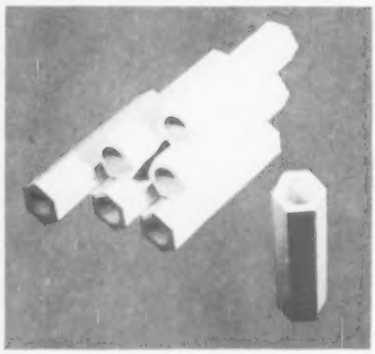


BeO









CURTISS-WRIGHT BERYLLIUM OXIDE COMPONENTS

Capability to fabricate massive blocks and cylinders . . . thin wall tubes . . . complex shapes — has made the Research Division of Curtiss-Wright Corporation one of the nation's leading producers of beryllium oxide components.

Produced to customer specifications, Curtiss-Wright fabricated beryllium oxide shapes are designed to best utilize the outstanding nuclear properties and high temperature characteristics of beryllium in oxide form for reflectors, moderators, fuel elements and other applications.

The Research Division has already produced a full loading, consisting of 750 pounds of reflector elements, for the Curtiss-Wright built U. S. Army reactor at Watertown; production quantities of complex shapes for the 'Tory' II-A reactor experiment; and prototype fuel elements for several gas cooled reactors.

Fabricating and laboratory facilities of the Research Division are producing the refractory shapes of today — are equipped to fabricate the nuclear shapes of tomorrow.

AD NO. 59-1

RESEARCH DIVISION **CURTISS-WRIGHT CORPORATION** **QUEHANNA, PENNSYLVANIA**

be the dominant mechanism of failure rather than dissolution of the cladding by the molten uranium. Experimental results seem to be consistent with this prediction.

Fermi-Sample Results

The basic Fermi-1 fuel element (*10*) consists of 10 wt% molybdenum-uranium in the form of a 0.374-cm-diameter cylinder metallurgically bonded to 0.13-mm-thick zirconium cladding with zirconium end caps. Over-all length, including zirconium ends, is 81.5 cm.

For TREAT experiments, half-length fuel cylinders were used, capped with regular end fittings. The over-all length, comparable to that of EBR-2 elements, permitted the use of standard, opaque dry capsules in meltdown experiments. Because of the absence of bond sodium, no pressure transducers were included in the capsules. The first nine samples were given short power bursts. Four of these were not instrumented with Pt–Pt-Rh cladding thermocouples because of the fear that welding such thermocouple wire to the thin zirconium cladding might trigger failure by weakening the wall at the attachment points. Of the remaining five elements, all lost their thermocouples at or near the melting point apparently because of expansion of the cladding. Hence, the maximum cladding temperatures were estimated, except for one sample that just reached the melting range.

The results of these nine experiments offer an interesting contrast to those of the tests obtained on EBR-2 elements. The results can be summarized as follows:

First, samples could be carried past the fuel melting point without failure occurring. Considerable warpage was noted in such cases, however. Mild failure was noted beginning at an estimated maximum temperature of ~1,250° C. In one test, a small amount of liquid fuel alloy flowed under the influence of gravity from a small flaw in the cladding and solidified on the outer surface of the cladding.

As the maximum temperatures increased, the quantity of fuel escaping and the magnitude of the cladding failure also increased. Figure 2 depicts the extensive failure and attack of cladding observed for the higher maximum temperatures. The more severely attacked sample reached the

(*Continued on page 150*)

New VALCOR Solenoid Valve For RADIO-ISOTOPE PROCESSING

Controls radio-active Nitric Acid, Hydrogen Peroxide, Ammonium Hydroxide, Sulphuric Acid, Sodium Hydroxide, etc.

Valcor's new solenoid valve for radio-isotope processing now handles a wide variety of radioactive corrosive chemical solutions — **even in a radiation field as high as 25 million rads!** Available in standard ¼" pipe sizes, and up to ¾" in specials. Designed for normally closed and normally open applications in all normal AC and DC voltages. Ideal for use in pressure and vacuum systems. Write today for further technical data #RV plus Valcor's free 16-page booklet telling how to select solenoid valves for over 500 corrosive media!

VALCOR SOLENOID VALVES

VALCOR ENGINEERING CORP.

5361 Carnegie Avenue • Kenilworth, New Jersey • CHestnut 5-1665

Mandrel-Movement Detector Reduces Cost of Breaks

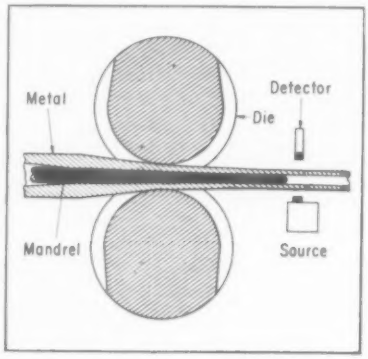
The customer saved $6,000 in ½ sec. So says Tracerlab of a system installed to detect mandrel movement in a cold-rolling mill before the broken mandrel could permit the machinery to smash itself up.

A mandrel is part of a machine that makes seamless tubing. As shown in the figure metal flows over the mandrel. Meanwhile two dies, moving in a reciprocating manner, push the metal against the mandrel to form the tubing. Since the mandrel is covered by the metal that is being made into tubing, it is hard to tell when it breaks. But when it breaks, the dies come together, and the damage is extensive and costly.

The problem that was solved was to detect a movement of less than 0.1 in. and shut down the machinery before the movement became as great as 0.5 in. Moreover the system must operate in a brutal oil-mist atmosphere, and be protected against vibration and shock.

Cesium source. Since the radiation has to penetrate through more than 30 gm/cm² of material, Cs^{137} (0.662-Mev gammas, 27-year half-life) was selected to supply it. 45 mc was deposited as cesium chloroplatinate on a ceramic disk, covered with a protective coating of sodium silicate, surrounded by an aluminum sheath and sealed into a thin-window stainless-steel capsule. The aluminum is there to react with any chlorine that might be freed by chemical breakdown of the source. The source capsule goes into a 50-lb cast-iron mount with a motor-driven lead rotor that exposes the source when it is needed and shields it when it is not.

The detector is a halogen quenched, gamma-sensitive G-M tube. With an oil-tight, shock resistant mount it is only 10 in. long. Within the mount is a transistor rate meter with a logarithmic response so that the unit can be used hundreds of feet from its control console and connected to it only by telephone cable. Sensitive volume is $\frac{1}{20}$ in³, and life expectancy is $>10^{10}$ counts.



GAMMA GAGE detects mandrel movement

Should We Be Stockpiling Uncontaminated Materials?

Will we some day look back to the good old days when we could make a low-level counter with nonradioactive aluminum, fill it with nonradioactive gas, shield it with nonradioactive steel and treat it with nonradioactive reagents? If this is a threat, what should we be doing about it? At least two groups are actively evaluating problems that are arising or may arise from introducing man-made radioactivity into our environment; one is a committee of the International Commission on Radiological Units under N. G. Trott of the Royal Cancer Hospital, London; the other is the Subcommittee on Radiochemistry of the Committee on Nuclear Science of the National Research Council under W. Wayne Meinke, University of Michigan. Under the sponsorship of the Subcommittee on Radiochemistry, J. R. DeVoe has spent more than a year gathering information on problems of this nature, and will continue to do so at least until next June.

Introduction of man-made radioactivity produces many problems:

Low-level counting. Materials for making counters, shielding them and filling them may become hard to find. For example, krypton is already sufficiently contaminated with Kr^{85} from reactors to be unusable in low-level counters.

Radiochemical standards. The radiochemist has two kinds of problems: (a) to keep radioactivity concentrations small for some purposes and (b) to know accurately what they are for others. The matter extends further; for some purposes a chemist would like to know that natural isotopic ratios have not been upset by the nuclear age. Already marketed lithium compounds are altered enough from prenuclear days to affect gravimetric factors.

Photography. Requirements of the photographic industry are perhaps more severe than any others. Emulsions, films, wrapping papers and even cameras must be made of materials in which there is no accidental contamination with particulate radioactivity.

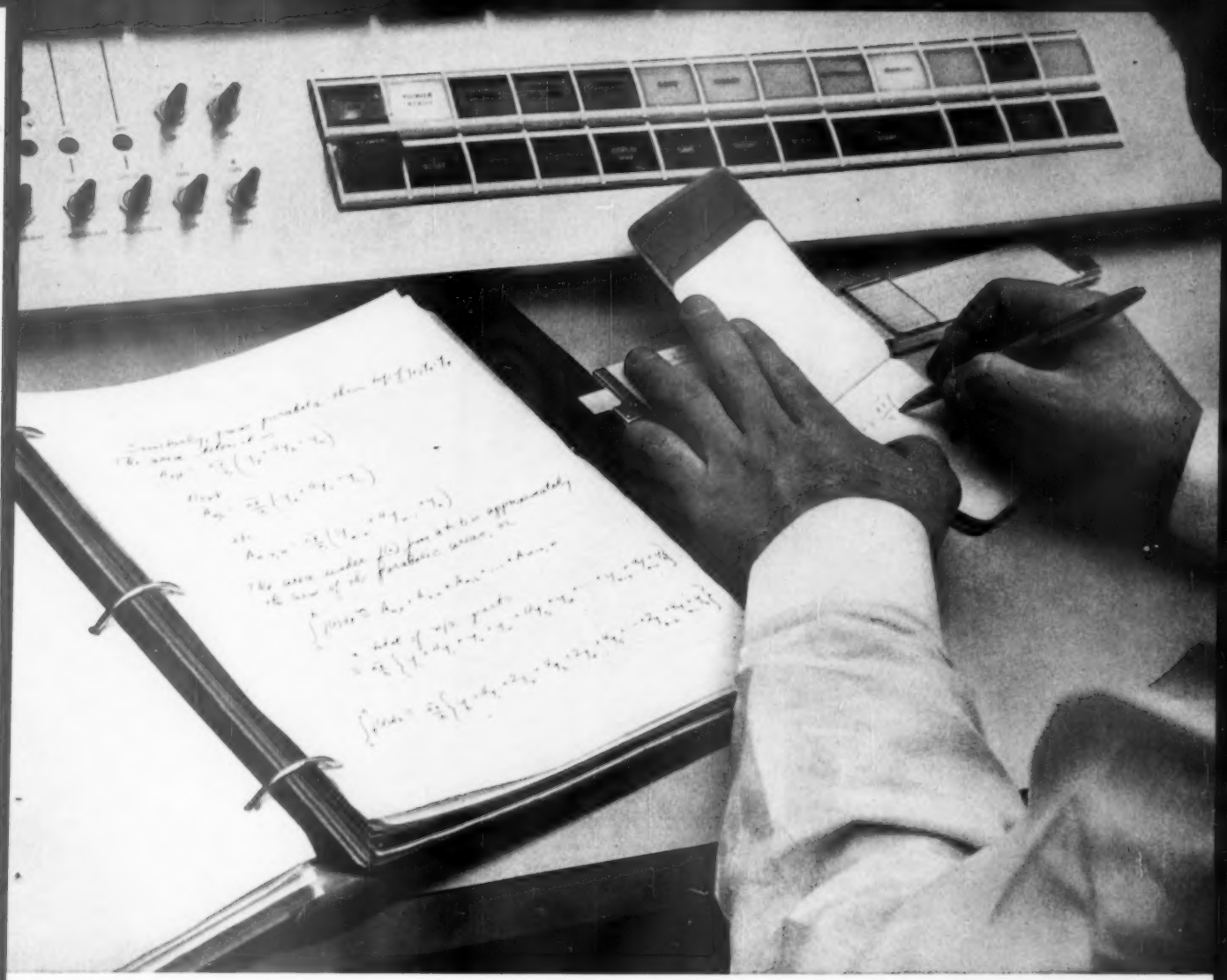
Problems Arise

It is easier to see the magnitudes of contamination problems by looking back on them than by anticipating them, but sometimes it is too late to do something about the ones that you can look back on. The photographic industry ran into an extreme example during World War II. Airplanes needed a huge increase in radium-coated dials. Paper covered the bench tops used in the work. Since the paper-salvage program fed all of these bench covers back into paper stocks, all paper in the country became contaminated enough to be unusable in photography. Special cleaning of certain paper mills solved the difficulty until new contamination appeared with the Alamogordo bomb of July, 1945. Now the industry handles the problem with close monitoring, testing and timing of paper-mill runs relative to bomb tests.

What to Do

Stockpiling of unadulterated materials may be the way to meet radioactive-contamination problems, but there are many who do not think so. Alternative procedures are to decontaminate when necessary and produce virgin materials from uncontaminated ores. Instead of reducing levels to zero or near zero, it may be better to determine them accurately and catalog them.

Stockpiling of lead for shielding already occurs. In Holland shielding has been made from the lead of old churches and lead recovered from 200-yr-old shipwrecks (NU, Nov. '58, p. 197). The U. S. AEC is keeping



Free engineers for creative assignments with the new low-cost IBM 1620

The IBM 1620 Data Processing System is a low-cost solution to the problem of freeing engineers for their most creative and profitable assignments. Here's why:

EASY TO USE—Just a two-day training class is all you need to put your 1620 into operation. This means no delays in learning to use the 1620 computer.

In addition, you get a wide range of free programming services including FORTRAN and GOTRAN. FORTRAN is the powerful scientific language that lets you solve problems without writing detailed computer instructions. GOTRAN is a simplified language (a sub-set of FORTRAN) that lets you enter simplified problem statements and data into the computer with the solution immediately available, in one simple operation.

FAST—The 1620 solves a set of ten simultaneous equations in only 20 seconds. It inverts a 10 x 10 matrix in just 42 seconds.

POWERFUL—The 1620 inverts a 40 x 40 matrix. With optional additional core storage the 1620 can handle matrix inversion problems of a much higher magnitude.

GET FULL DETAILS—The 1620 is the most outstanding engineering and scientific computer in its price range. A basic installation rents for just $1,600 a month.

To learn how the 1620 can free you for more creative engineering work, call your local IBM representative.

IBM's 1620 is a compact desk-size computer.

IBM
DATA PROCESSING

Christiaan Huygens
1629-1695

The Dutchman who could WALK THROUGH WALLS

For Christiaan Huygens the barrier between "pure" and "applied" research was as insubstantial as a rainbow. He made an intensive study of the theory of probabilities. He invented the pendulum clock. He perfected the telescopic lens. He made monumental contributions to geometrical optics and to "pure" light-wave theory.

The freely ranging imagination of an orderly mind in a stimulating intellectual climate has a way of dissolving artificial barriers. It happens every day in Los Alamos.

For employment information write:
Personnel Director Division 61-37

los alamos
scientific laboratory
OF THE UNIVERSITY OF CALIFORNIA
LOS ALAMOS, NEW MEXICO

Stockpiling

This article starts on page 122

available several tons of old lead from a sulfuric-acid plant. Some persons suggest a stockpile of all of the 57 elements having isotopes with half-lives greater than two months. Ten of these elements are exotic and expensive; one would stockpile about a pound of each of them. Of the others one would store 100 lb of each. Estimated costs of the stockpile average about $1,000 per element. The problem of disposal would arise.

Meanwhile there are counterarguments. Zero-mass and all-plastic beta counters may make contamination-free materials unnecessary for beta counters. This does not apply to scintillators; it probably makes sense to store non-radioactive sodium iodide. Perhaps the strongest argument of all is that with all its inconvenience a stockpiling program would not meet the need. The photographic industry feels that it would be totally inadequate for their purposes. Even counter makers feel it might not serve them.

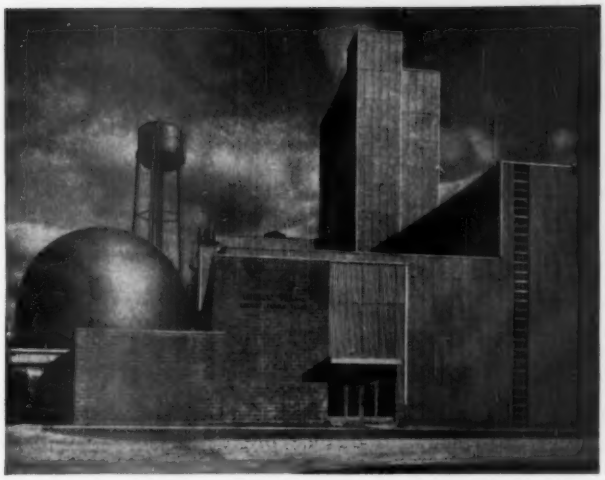
Laboratory Experiments Teach Tracer Techniques

Today's applied-radiation student and tomorrow's applied-radiation engineer can now introduce himself to his subject with a set of laboratory experiments prepared especially for his needs. The collection is available in an attractive 184-page paper-covered book ("Radioisotope Experiments for the Chemistry Curriculum") prepared by Nuclear-Chicago Corp. under contract to the Office of Isotopes Development, AEC.

All that the student (or instructor) needs to perform the experiments is a G-M tube, scalar, timer and an inexpensive package of 13 radioactive compounds. He need not have previous experience or an AEC license.

The book starts with 34 pages of general material (what is radioactivity? how do you use and handle it?) and then goes on to explain 23 experiments in detail. Experiments are presented in groups: ten general introductory ones, three for introductory chemistry, three for qualitative analysis, etc.

Nuclear-Chicago is offering free copies of the book and a set of instructor's notes to college and university teachers. Additional copies can be bought from Nuclear-Chicago or the Office of Technical Services, Washington 25 ($1 for notes, $2 for book).



Exterior View of the Enrico Fermi Atomic Power Plant, Built Near Monroe, Mich. by The Power Reactor Development Corporation.

G-R

First of its kind

VERTICAL ONCE-THROUGH INVOLUTE TUBE

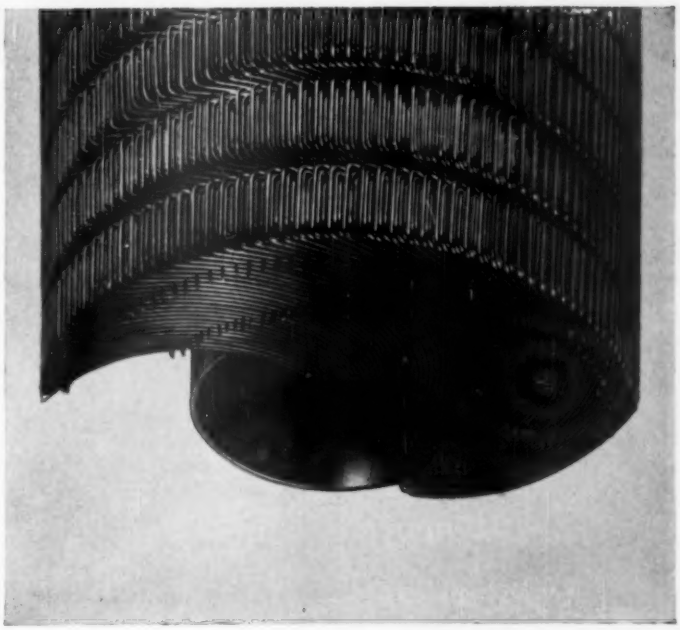
Liquid Sodium Heated Steam Generator

Installed at Enrico Fermi Atomic Power Plant

Conceived and engineered by Griscom-Russell and fabricated in the Griscom-Russell plant, this new type of sodium heated steam generator underscores the ingenuity of Griscom-Russell designers and fabricators in pioneering new, uncharted areas of heat transfer. The involute curved tubes, with U-bends to make 14 horizontal passes between the thermal shield and shell, present even tube spacing to the sodium flow to promote even flow distribution, assure high heat transfer and avoid interferences from thermal expansion.

Three of these new generators of identical design and construction are completing final tests at the Enrico Fermi Atomic Power Plant. Each provides 10,962 square feet of effective surface, and will transfer 489,000,000 BTU/Hr.

For more complete description of these new units, and views of their shop fabrication, write for the Winter 1960-61 edition of G-R News. Send for your copy today.



Bottom of a Partially Assembled Tube Bundle Showing the Involute Curve of the Tube Banks.

Griscom-Russell

THE GRISCOM-RUSSELL COMPANY

220 Wetmore Ave. **Massillon, Ohio** Telephone TE 2-8751

Engineering and Sales Representatives in the Principal Cities

Radioautographs Show Quality of Panel Brazing

By B. H. FAULKENBERRY, R. H. JOHNSON and C. E. COLE*
Norair, a Division of Northrop Corp., Hawthorne, California

Widespread use of stainless-steel honeycomb sandwich assemblies for light, strong, temperature-resistant structural members in supersonic aircraft, missiles and space vehicles has created a demand for nondestructive quality-control inspection. A radioautographic technique that we have developed shows excellent promise, especially for curved assemblies or those of complex shape, with which exterior inspection devices have focusing problems. Some further investigation will be required to adapt our method to high-temperature alloys now being proposed for honeycomb panels.

As shown in Fig. 1, our sandwich panels consist of conventional components: an outer metal skin, brazing foil (0.002 in. thick) and honeycomb core (0.75 in. thick). When such panels are assembled and heated, the brazing alloy melts and flows into fillets around the core, also creeping into parts of the core by a combination of gravity and capillary action. Initial calculations on the amount of brazing material collecting in fillets of such assemblies indicate that the amount is ~⅔ of the total alloy.

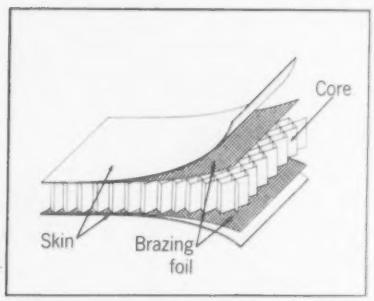


FIG. 1. HONEYCOMB PANELS are sandwiches with top and bottom skin brazed to central core. Brazing metal inserted as foil runs into fillet at joints when heated

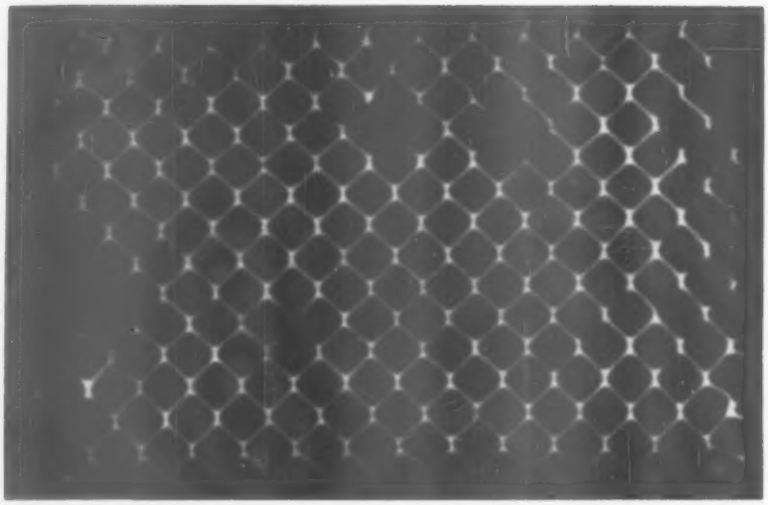


FIG. 2. Sb^{124} RADIOAUTOGRAPH had 2-hr exposure on Type A film and activity of 1.8 $\mu c/in^2$ in foil. Defects at top center were intentional; others were accidental. Method is valuable for simplicity and clear visual indication of brazing quality. Brazing foil can be labeled by neutron activation, mixing of radiotracer with brazing metal or electroplating

We used two methods to braze our panels. One is the conventional process with a vacuum oven; the other used radiant heating.

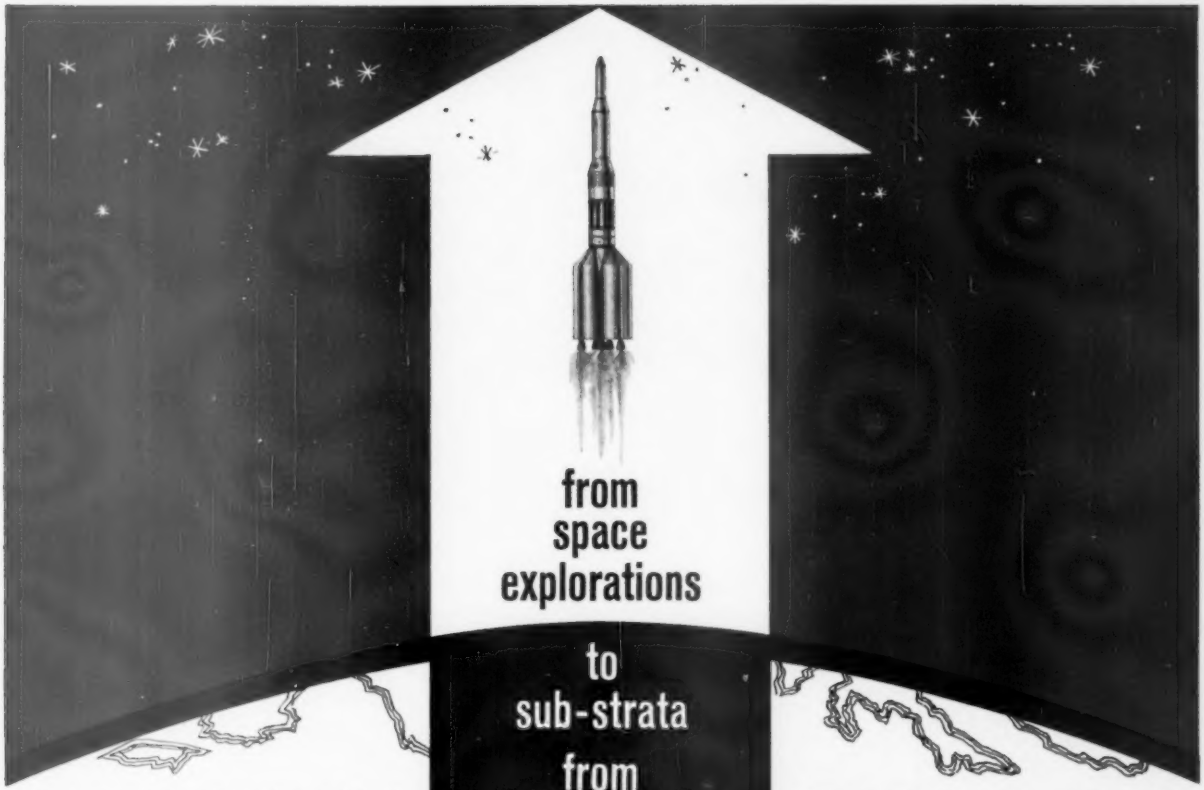
Our inspection method consists in tagging the brazing foil with radioactive Ag^{111}, Au^{198} or Sb^{124} and then making radioautographs of both sides of the finished panel. Both sides of a panel can be radioautographed simultaneously without noticeable fogging of the film from the activity on the opposite side. We get clear, well-defined radioautographs with foils that have an activity of 1–5 $\mu c/in^2$ and exposure times of 2–20 hr. The small amounts of tracer required to make good radioautographs do not alter bonding properties of the film.

Tagging of Brazing Alloy

We considered three methods by which the brazing alloy could be made radioactive: (a) mixing the radiotracer with the molten alloy and then rolling the alloy into sheet form, (b) irradiation activation and (c) electroplating the radioactive material onto the brazing foil. We actually used the electroplating process for silver and gold tracers and the mixing method for antimony. In an ultimate production process, we feel that the mixing method would be best. Since the chemical composition of the foil is 92.8% silver, 7% copper and 0.2% lithium, possible nuclides that would be useful tracers in the foil after activation are Ag^{108}, Ag^{110m}, Ag^{110}, Cu^{64} and Cu^{66}.

Before electroplating the brazing alloy we cleaned it. Upon rinsing and

* PRESENT ADDRESS: Graduate School, University of California at Los Angeles.



from space explorations to sub-strata from infrared to ultraviolet

MULTIPLIER PHOTOTUBES by DU MONT

Du Mont offers the most complete variety of physical and electrical characteristics in Multiplier Phototubes available—for applications from space exploration to sub-strata work. In addition to a complete line, Du Mont's technical knowledge and engineering skill is available for custom designs and development.

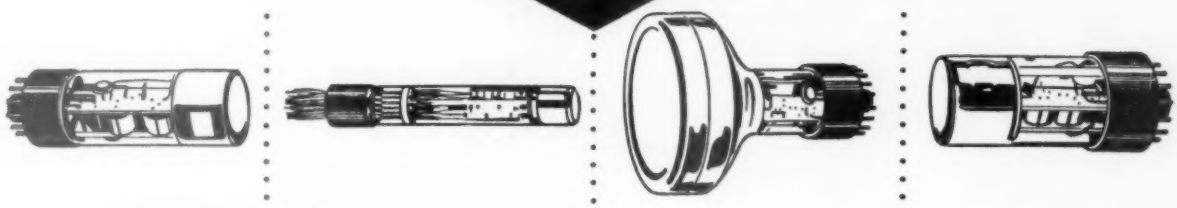
Du Mont Multiplier Phototubes have earned great acceptance in such fields as rocket and missile exploration and guidance, scintillation counting, analysis of low-level light sources, oil exploration, spectroscopy, and in many other applications requiring performance under arduous environmental conditions.

For any application in the spectrum—from infrared to ultraviolet—Du Mont manufacturers Multiplier Phototubes to meet all requirements. Consultation on your specific application is welcomed.

FEATURES

- Ruggedized construction
- Photocathode diameters from ¾" to 21"
- Selection in number of dynodes
- Encapsulated voltage dividers in base
- Choice of secondary emissive surfaces

Write for complete details
Tube Sales Department



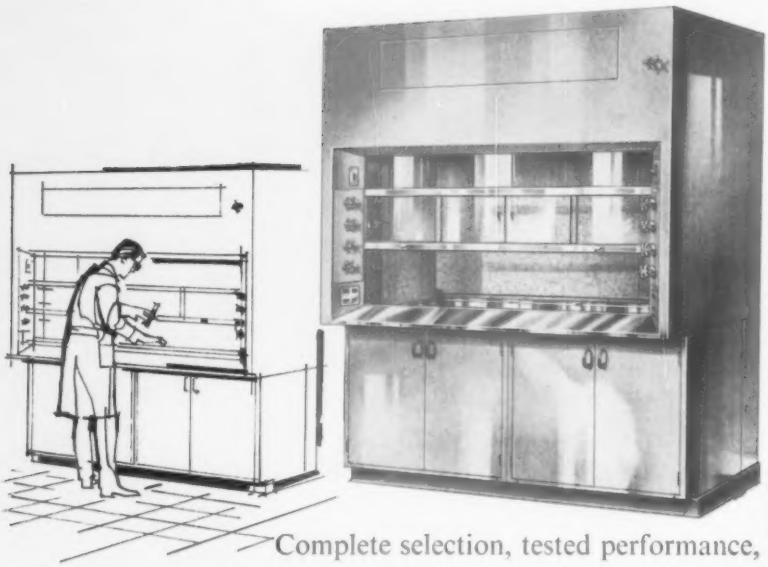
DU MONT

ALLEN B. DU MONT LABORATORIES, Clifton, N. J.

TUBE SALES DEPARTMENT

DIVISIONS OF FAIRCHILD CAMERA AND INSTRUMENT CORPORATION

DU MONT INTERNATIONAL DIVISION, 515 MADISON AVENUE, NEW YORK 22, N. Y. CABLE: ALBEEDU



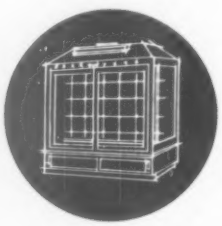
Complete selection, tested performance, precision engineering, and proven results are offered by

HAMILTON LABORATORY FUME HOODS.

Included in the standard hood structures are: conventional, air-foil, balanced air, radiation and perchloric acid designs, supplied in open or sash-front construction. *Where your requirements call for individually designed fume hood structures,* our experienced technical and air conditioning consultants are at your service, without obligation, to plan your most exacting installations. These specialists are constantly developing and testing new types of structures including Complete Control Cabinets and Radio-Chemistry Safety Enclosures that meet the most critical needs of growing scientific advances. For complete data, and experienced assistance, we invite you to write or call Dept. 331.

COMPLETE CONTROL SYSTEMS

LABORATORY EQUIPMENT



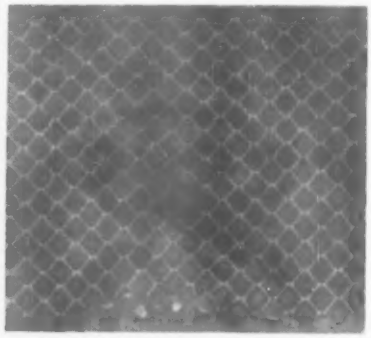
CALIFORNIA TYPE RADIATION FUME HOODS

Hamilton

PROFESSIONAL AND SCIENTIFIC FURNITURE

new dimensions in time and space efficiency for: physicians; dentists; industrial, hospital, school laboratories; draftsmen; printers; libraries; home laundries.

Hamilton Manufacturing Company, Two Rivers, Wisconsin



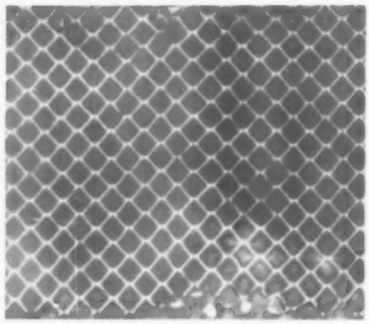


FIG. 3. Ag^{111} RADIOAUTOGRAPHS show brazing failures through 0.01-in. skin. Exposures are 4 and 6 hr on Kodak Type A industrial X-ray film. Brazing foil had an activity level of 4.74 $\mu c/in^2$

drying, the alloy was immersed in the appropriate plating bath and electroplated with the selected tracer. A small amount of the stable isotope was usually added to the plating bath as a carrier to facilitate plating of the radioactive material. But good results were obtained in plating Ag^{111} without addition of a carrier.

Silver plating. Chemical composition of the Ag^{111} plating solution is as follows: (a) 90 oz sodium carbonate, (b) 96 oz sodium cyanide, (c) 15 gal distilled water, (d) 1 mc of Ag^{111} in the chemical form of silver nitrate. We used stainless-steel anodes to avoid introduction of nonradioactive silver into the solution.

The brazing foil was immersed in the plating solution and a current of 10 amp was maintained in the solution for a period of 8 hr. This removed 98% of the radioactive silver from the plating solution. The adhesion of the silver to the foil was poor, and the plate had a soft spongy appearance.

(*Continued*)

Gold plating. A Sel-Rex Karatclad No. 369 Acid Bright Alloy gold plating process was used for plating radioactive Au^{198} onto the brazing foil. The solution is commercially available (Sel-Rex Corp., 75 River Road, Nutley 10, N. J.). Each panel was plated at 1.1 amp for 5 min. The resultant deposit was hard and shiny. Adhesion to the base foil was good.

Radioautographic Inspection

After the panels had been brazed, a sheet of photographic film was placed on each surface and allowed to sit until sufficient exposure was obtained. The exposure time required for a good radioautograph varied and depended on the radiotracer, thickness of panel skins, photograph film and amount of activity per unit area of brazing foil.

We varied the thickness of the metal skins from panel to panel according to which radiotracer was used to tag the brazing alloy. Ag^{111} emits a 1.04-Mev beta (91% of its disintegrations), and the maximum steel skin thickness that it will penetrate is ~0.20 in. Au^{198} emits a 0.411-Mev gamma photon (99%) and Sb^{124} emits 0.12-, 0.607-, 1.71- and 2.04-Mev photons. With the emissions characteristic of gold and antimony, the skin thickness is not limited as it is with Ag^{111}.

Radioautographs

As you will see from Figs. 2 and 3, the particular value of the method lies in the visual clarity of the radioautographs and the ease with which voids and other defects can be detected in the brazed panel. In Fig. 2, for example, large defects in the upper center were intentional; the remainder were not. Subsequent investigations enabled a complete correlation between indicated and actual defects.

Is It Safe?

The radioactive hazards associated with a procedure of this type are functions of the tracer selected and the inspection time agreed upon. Safety problems can be reduced with short-half-life materials; but the radionuclide must have a sufficiently long half-life to permit all radioautographic applications to be completed. Theoretically, an average exposure period of 20 hr and an average surface dose of 5 mr/hr are enough.

This order of magnitude has been confirmed by one of the test panels. The average surface dose in this panel, as measured by a G-M survey meter, was 7.5 mr/hr at the time of film expo-

Complete Instrumentation in Nuclear Measurement

EKCO

EKCO for RADIATION MEASUREMENTS: The nameplate Ekco Electronics, Ltd. appears on instruments of wide application and diversified design in almost every country of the world. This nameplate is assurance of the very best in concept, workmanship and capability.

N616 ELECTROMETER

Head amplifier permits immediate selection 10^{12}, 10^{10}, 10^{8} resistors, plus open circuit for rate of charge measurement. 7 ranges each full scale from 3 mv to 3 volts: 100 uv stability day to day ±2% accuracy for voltage measurements. Recorder output. Full test facilities.

N664 SCINTILLATION COUNTER

The truly universal Scintillation Counter for use with EKCO scalers and ratemeters and instruments of comparable ability. Has inbuilt linear amplifier. Extremely sensitive and efficient for counting of tritium and other weak isotopes in liquid form. Ideal for routine gamma counting with solid or well-type crystals. Compact, dependable and proven.

N530 SCALER

Preset time and preset count. Six decade automatic scaler with precision discriminator and stable H.V. to 2,000 volts. Large meter monitors H.V. and discriminator voltages. 5 us resolution input sensitivity .1 volt neg. or 5 volts pos. Push buttons also provide start, stop, reset, test 1 cps, test 60 cps. The perfect instrument for most scintillation and GM counting.

N600 RATEMETER

Plug-in assembly in a compact versatile package. 10 ranges 3 cps to 100,000 cps full scale with mean probable error control from 1% to 10%. P.H.A. section provided with variable gate in voltage 0–100 and 0–100% of threshold with manual and automatic scan. Fast recovery from overload. Linear amplifier from 25–1,000 times with stable H.V. up to 2,000. AMP input sensitivity .5 mv to 2 negative, 5 volts to 100 positive. Recorder output.

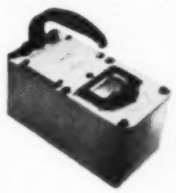
N596 RADIATION MONITOR

Operates on standard batteries. Ionization chamber of high sensitivity; 0–3 mrads, 0–30 mrads, 0–300 mrads plus integrating range of 0–30 mrads with a time constant of 15 hours. Measure, Beta 3 MEV to 500 KEV and Gamma 3 MEV to 10 KEV with 10% accuracy. Chamber especially designed to approximate physiological dose-rate.

- Linear Amplifiers
- Geiger Pre-amps
- Geiger Probes
- High-Resistance Measuring Set
- Manual Scalers
- Standard Ratemeters
- Beta-Gamma Monitors
- C.D. Radiation Monitors
- Medical Scintillation Counters
- Sodium Iodide Crystals
- Sample Ovens
- Pulse Analyzers
- Coincidence Units
- Portable Scalers

- Reactor Period Meters
- Log Gamma Monitors
- Thermocouple Trip Amplifiers
- Fast Neutron Heads
- Effluent Monitors
- Shut Down Amplifiers
- Power Error Meters

- Nuclear Transmission Gauges
- Backscatter Gauges
- Pipe-wall Portable Gauges
- Fluid Density Gauges
- Proportional Controllers
- Limit Alarms



N578 SLOW NEUTRON MONITOR

Measures dose rate from slow neutron 0–15 mrem/hr to 0–150 mr with inbuilt calibration source. Scales calibrated and direct reading. 80–1 discrimination against gamma dose rate. Energy range to 30 eV. One second time constant.

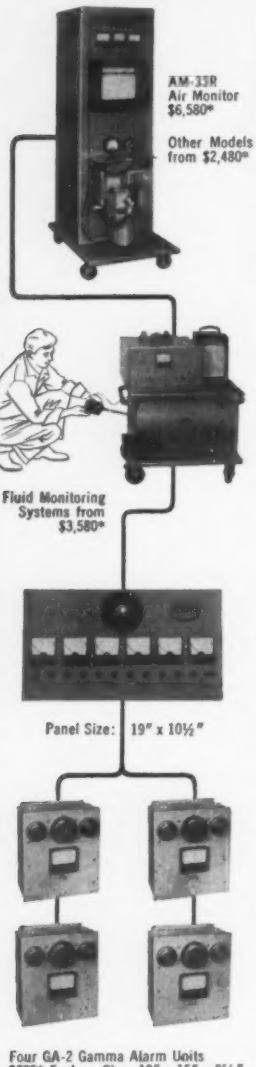
EKCO ELECTRONICS, LTD.

In U. S. A., address all inquiries to:
American Tradair Corporation, 34-01 30th Street,
Long Island City 6, New York
ELSEWHERE: Ekco Electronics Ltd., Southend, England

Monitoring Systems

DESIGNED, BUILT AND BACKED BY NMC INDIANAPOLIS, INDIANA

What is your radiation monitoring problem? Airborne particulates . . . gaseous or liquid radiation . . . or gamma area radiation? NMC equipment can monitor any one or all with individual units or complete systems. The system shown here presents data at each station and on a control room follow meter panel. It warns of caution and alarm levels; can even operate emergency controls.



AIR MONITORS

NMC air monitors offer many exclusive advantages. For example, Model AM-33R shown here detects and identifies long half-life emitters directly, almost immediately, with one detector. Other monitors require five hours or more for identification, due to the natural radon progeny. The four NMC models are . . .

MODEL	CHANNELS	FILTERS	ACTIVITY DETECTED
AM-2A	1	Fixed	α, $\beta\gamma$ or γ
AM-3A	1	Moving	α, $\beta\gamma$ or γ
AM-22R	3	Fixed	α and $\beta\gamma$ Shows ratio of $\beta\gamma/\alpha$
AM-33R	3	Moving	α and $\beta\gamma$ Shows ratio of $\beta\gamma/\alpha$

FLUID MONITORS

The NMC fluid monitoring system detects radioactivity in gas or water at MAC levels. Used with an NMC air monitor, it measures activity of the gaseous component of the discharge from the air monitor. Contamination and a separate pumping system are eliminated by employing the air pumping system and filter mechanism of the air monitor. The fluid system includes the FMS-1 shield with 30 liter sampling chamber, and two detectors—GM or NaI scintillation—operating in parallel; the LCRM-2M logarithmic count ratemeter with built-in bell and alarm lights; and portable EA graphic recorder.

FOLLOW METER PANELS

Each monitoring station can be connected to a follow meter panel in the central control room with inexpensive unshielded standard electric code wiring. There's a meter for each station to show the radioactivity being detected, and lights to indicate caution and alarm levels. The bell sounds for an alarm condition at any station. Multipoint recorders and remote emergency controls may be connected to the panel.

AREA MONITORS

Each of the four GA-2 units shown here is a complete monitoring station that indicates and reports unusual or excessive gamma radiation. It mounts on the wall and wires to any 110-volt circuit, eliminating the central power supply required by other systems. Each GA-2 has an amber and red light, bell, indicating meter, and complete alarm system. Units readily adapt to a complete system. They connect to follow meters and graphic recorders; are interchangeable without the usual installation matching and calibration. They are not sensitive to temperature, line voltage changes or external electro-magnetic radiation. The amber light is also a fail-save device, signaling component failure. An auxiliary power supply for each GA-2 is available.

**All Prices fob, Indianapolis • For full details, write, wire or phone collect*—LIBERTY 6-2415

Nuclear Measurements Corp.
2460 N. Arlington Avenue • Indianapolis 18, Indiana
International Office: 13 E. 40th Street, New York 16, N.Y.
NMC INDIANAPOLIS

Panel Brazing

This article starts on page 126

sure. The dose becomes smaller with distance from the panel, and at 6 in. it is down to 1 mr/hr.

Foreseeable controls for a production operation using radioactive gold or silver amount to film-badge service and protective gloves for the personnel handling the brazing alloy and performing the brazing. After this the radioactive material is treated as a sealed source, with the level sufficiently low to allow normal handling.

What Does it Cost?

The cost of this mode of inspection is competitive with those of inspection methods that are currently being used in industry. Actual cost of radioactive gold material for tagging the brazing alloy will vary from 10 to 20 ¢/ft² for a continuous production run. Film costs average ~75 ¢/ft². On this basis production material costs would total about $2/ft² of panel, and it appears reasonable that continuous radioautographic inspection could be accomplished for $4–5/ft² of panel. Costs for small quantity and intermittent production would be slightly greater because of fixed-cost items. Cost-reducing refinements can be imagined in the application of this technique; the film might be attached to the assembly during its normal production-line movements and removed at a later station, permitting complete and accurate production inspection in minimum time.

Advantages

Radioautographic inspection is adaptable to any type brazing alloy regardless of density. It is simple and does not require the use of highly qualified inspection personnel. Film need only be applied, then later removed and developed. Radioautographs are easily read; they indicate at a glance heavily and lightly filleted areas. They do not indicate a bond but only the presence of material. The method presupposes that the presence of a fillet of brazing alloy indicates a bond. This appears logical, however, since the alloy must wet the adjacent surfaces in order to form the fillet. The autoradiographs presently do not indicate node flow. Additional comparative work may reveal a useable relationship between the density of the exposed film at the node and the amount of node flow.

SCIAKY...
FIRST IN ELECTRON BEAM WELDING

Advanced Sciaky Design Combines Research and Production Capabilities into One Machine

If *you're* interested in electron beam welding, here's why you should investigate Sciaky machines:

SCIAKY ELECTRON GUN DESIGN...

Simple, rugged and compact! Exceptional electron optics produce beam density previously possible *only* with accelerating potentials as high as 100,000 v. The Sciaky gun, entirely contained within the atmosphere of the welding chamber, will operate in any angular position. *Both* gun and fixture can be moved to any position within the chamber while welding. Advanced focusing design results in welds with 12 to 1 depth to width characteristics.

SCIAKY PUMPING SYSTEM...

Fast and efficient! Depending on chamber, only 3 to 10 minutes are needed to evacuate chamber to welding pressure. Pumping sequence is *completely* automatic with built-in safety devices.

SCIAKY SAFETY...

Unmatched! Low voltage (30,000 v. maximum) and highly refined chamber design eliminates x-ray hazards, which are a severe problem with higher voltage equipment. No costly shielding is needed.

Call or write for details of these and other Sciaky machine features. Regardless of your specific area of interest, you'll find Sciaky's combination of extensive welding experience and advanced electron beam technology to be helpful.

Sciaky is Exclusive Licensee under the Stohr U.S. Patent 2,932,720

80C6102

You can learn more about Sciaky Electron Beam Welding, fully automatic TIG and MIG Welding with modular or building block concept, and the newest in Bench Welding at the

A.W.S. Welding Show, New York Colliseum, April 18, 19, 20, Booth 729

SCIAKY BROS., INC., 4944 WEST 67th STREET, CHICAGO 38, ILLINOIS • PORTSMOUTH 7-5600

Manco Special Hydraulic Devices

for nuclear processes

- The unit illustrated is used in the salvage severance of obsolete pipelines. In actual use the cutting head is suspended in the "hot" area and is operated by remote control. It is controllable in a manipulator "wrist action" for positioning between manifolded pipe headers. In less than 10 seconds it will cut 4" O.D. x .226 wall Inconel pipe at room temperature. Your inquiry on units of this type or for the development of other special equipment involving high pressure hydraulics would be welcome.

Write for Complete Information

MANCO

MFG. CO.
BRADLEY, ILLINOIS

Recent Advances in Nuclear and Radio-Chemistry

By T. ALEXANDER EASTWOOD
Atomic Energy of Canada Ltd., Chalk River, Ontario, Canada

Significant advances are currently being made in the study of the ranges of energetic heavy ions in solids and in their application to the interpretation of fission and other nuclear-reaction mechanisms. This, as well as fission-product mass and charge distribution, heavy-ion interactions and cross-section measurements, were discussed at the Third Symposium of the Chemical Institute of Canada on Nuclear and Radiochemistry.*

Heavy-Atom Interactions

A study of the heavy atoms recoiling from a nuclear reaction can give important information about the mechanism of the reaction. Since the recoil atoms are detected by their radioactive decay characteristics, the method is usually highly specific. In addition, range measurements provide information about the kinetic energy of the nuclei.

In the past, the precise interpretation of range measurements has not been entirely satisfactory because it was based on rather scanty experimental results and the purely theoretical treatment of Bohr, Lindhard and Schaarf. Recent work described by D. Powers (CIT)† and J. A. Davies (AECL) has done much to improve the situation for atoms in the energy range 5–500 kev.

Powers has studied the ranges of atoms of nitrogen and of inert gases in Be, B, C and Al targets. The range and range straggling were deduced from momentum analysis of protons scattered from the embedded atoms. The results showed departures from theoretical expectations, which was attributed to the fact that theory predicts total ranges but experiment measures only the perpendicular component of the range.

Davies reported range measurements of alkali metal ions in aluminum. A polished aluminum surface was bombarded with radioactive ions, and the depth of penetration was determined by measuring the radioactivity in successive thin layers removed from the target by electrolytic anodization followed by dissolution. He showed that the theory of stopping when refined to take into account the finite number of collisions made by the heavy ion agrees with the observed distribution in range as well as the absolute value of the range. Davies presented a second paper that showed that the refined theory agrees well with the observed dependence of the range on the mass of isotopes of sodium.

Typical of the reaction mechanism studies that can be made using range measurements was the work described by R. A. Schmitt (GA). Sandwiches of metal target foils and aluminum catcher foils were irradiated with a bremsstrahlung spectrum of about 22-Mev maximum energy. The range of recoil atoms from the (γ,p) and (γ,n) reactions was obtained by γ-counting

* The symposium was held under the cosponsorship of the Inorganic Chemistry Div. of the Institute and Atomic Energy of Canada Ltd. at the Chalk River Laboratories of AECL on Sept. 6–8, 1960. Many of the contributions were published in the February issue of the Canadian Journal of Chemistry.

† Addresses of conference contributors:

AECL = Atomic Energy of Canada Ltd., Chalk River, Ontario, Canada
AERE = Atomic Energy Research Establishment, Harwell, England
AWRE = Atomic Weapons Research Establishment, Aldermaston, England
CIT = California Institute of Technology, Pasadena, Calif.
CU = Clark University, Worcester, Mass.
DU = Durham University, Durham, England
GA = General Atomic Div. of General Dynamics Corp., San Diego, Calif.
LRL = Lawrence Radiation Laboratory, University of California, Livermore, Calif.
NRC = National Research Council of Canada, Ottawa
UA = University of Alberta, Edmonton, Alberta, Canada

SILICON SURFACE BARRIER DETECTORS

FOR CHARGED PARTICLE AND NEUTRON COUNTING

- AREAS 0.14 TO 3.8 CM^2
- NO "DEAD" LAYER
- INDIVIDUAL PERFORMANCE TESTS
- DETAILED INSTRUCTION MANUAL
- Resolutions available to <20 kev FWHM for natural α's

STABLE LOW NOISE AMPLIFIERS

- Newest design, exclusive for ORTEC, by E. Fairstein

HIGH CURRENT R.F. ION SOURCES

FOR TECHNICAL BROCHURES, INFORMATION, AND SPECIAL SERVICES, WRITE

OAK RIDGE TECHNICAL ENTERPRISES CORPORATION

DEPT. AD3 P.O. BOX 524 TEL. 483-1935

OAK RIDGE—TENNESSEE

RCA 25 KW R-F Load and Wattmeter lets you measure power output up to 890 MC

Combines dummy load and r-f power measurement function—Power indication given directly in watts—Easily installed—Used in high power applications for many years.

A column of tap water is used for power dissipation. The input of the load consists of a polyethylene transformer section to match the connecting line. The opposite end of the line is short-circuited and contains the input and output water connections. Broadband wattmeters with scale ranges of 0 to 15 KW or 0 to 25 KW are available. These allow direct incident power readings, or with a 180° turn, a reading of the reflected power.

Write to RCA High Power Electronics and Nucleonics Department T-86, Building 15-1, Camden, New Jersey

EQUIPMENT NOW IN STOCK—AVAILABLE FOR IMMEDIATE DELIVERY

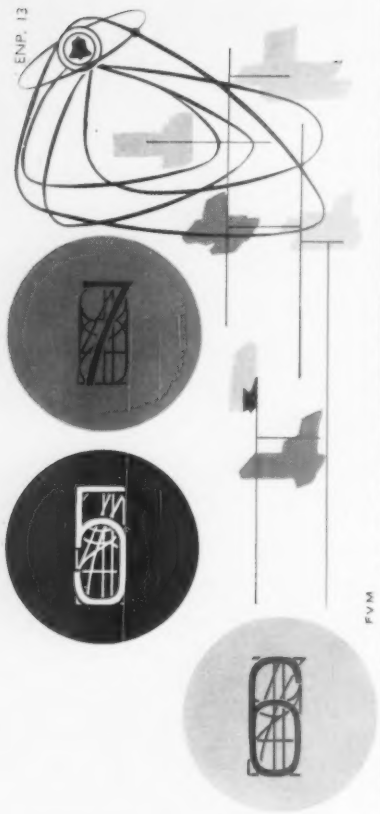
25 KW R-F Load Assembly for frequency range 470-890 megacycles . . . Specify MI-19198-A2	Price	$1,050.
25 KW R-F Load Assembly for frequency range 400-450 megacycles . . . Specify MI-28646	Price	$1,055.
15 KW R-F Wattmeter for use with above loads . . . Specify MI-27350	Price	$ 550.
25 KW R-F Wattmeter for use with above loads . . . Specify MI-27363	Price	$ 550.
Connector required to add wattmeter to load . . . Specify MI-19089-10	Price	$ 28.

Note: Special loads can be supplied for other frequencies on a custom basis.

RCA®

The Most Trusted Name in Electronics

RADIO CORPORATION OF AMERICA



ELECTRONICS FOR NUCLEONICS

SCALER CHRONOSCOPE

Bell Telephone scaler chronoscope gives you top quality reproduction of automatic counting and printing. It is so constructed that from a small stock of basic modules a wide scope of performances can be covered.
This type normally supplied in a metal case is also available for rack mounting

- preset time
- preset count
- result printing facilities
- interchangeable modules
- in line read out
- fully transistorized

Our staff is always available to answer your inquiries.

Bell Telephone Mfg Co

"Nuclear Energy division"
33, Berkenrodelei
HOBOKEN-Antwerp-BELGIUM

the catcher foils. The results indicate that the energy spectra of neutrons emitted from reactions involving target nuclides either on the nuclear-stability curve or on the neutron-rich side of the curve are very similar and have an average energy of about 2.3 Mev. Neutrons from photoreactions with neutron-deficient target nuclides appear to be more energetic. Angular-distribution studies were also made, and the results have been compared with theory to obtain the best values for certain parameters in the theory. T. Matsuo (CU) described how range measurements can be used to give information about the relative importance of "compound-nucleus" and "direct-interaction" mechanisms in certain (α,n) reactions.

Fission-Fragment Ranges

Range measurements have also been used extensively to study the nuclear-fission process.

J. A. Miskel (LRL) reported radiochemical studies of fission-fragment ranges. He found that the ranges of fragments from the spontaneous fission of Cf^{252} vary almost linearly with the mass number of the fragment. In contrast, the ranges of fragments from the symmetric thermal-neutron fission of U^{233} are relatively shorter than the ranges of fragments from asymmetric fission. G. N. Walton (AERE) reported confirmatory experiments made with U^{235}. Miskel pointed out that the range results are in accord with those obtained by fragment time-of-flight measurements. He suggested that if the correct division of charge rather than the most probable division of charge in fission could be taken into account, the observed difference in behavior of Cf^{252} and $U^{235} + n$ is what would be expected.

Walton explored several alternative explanations for the apparent deficiency in kinetic energy of the symmetric fragments from the neutron fission of U^{235}, including considerations of the ionization potentials of the elements in the region of symmetric and asymmetric division of mass, the energy carried off by the prompt neutrons, α-particles and γ-rays from fission, and the masses of the fragments involved. However a firm conclusion was not reached.

F. Brown (AECL) reported range measurements that showed that the kinetic energy of the fission mode which produces Cs^{136}, a nuclide formed as a primary fission fragment, is less than the normal value. It was suggested that the deficit could be accounted for by more-than-average neutron emission in the formation of Cs^{136}. Quantitative interpretation is not entirely satisfactory, however, because we cannot say, from our present state of knowledge, whether the distributions of neutron-emission probabilities for the two fragments are correlated or not. Furthermore, there are uncertainties about a prompt charge distribution and the precise range-energy relationship at these energies.

Chemical Interactions

Among the papers on the chemical interactions of energetic heavy atoms was a study of the chemical effects of the (n,γ) activation of bromine in alkyl bromides given by W. E. Harris (UA).

Harris reported results bearing on the tendency of molecules (1) to react with each other to give products with more carbon atoms than the parent molecule and (2) to form isomers by carbon skeletal rearrangement. The effects of large amounts of bromine scavenger were also described. He concludes that, in addition to the "thermal" and "hot" reactions postulated by earlier workers, a third type, "hot spot diffusive," are involved. Products formed by thermal reactions are defined as those that are readily eliminated by the addition of a small amount of scavenger, while products from hot reactions are not scavenged. Products from the hot-spot diffusive reactions are interfered with by scavenger but to a much smaller extent than the thermal. Hot-spot diffusive reactions are completely eliminated only by having a scavenger concentration approaching 100%.

Reaction Cross Sections

Nuclear-cross-section measurement, particularly with fast neutrons, is receiving considerable attention at present. Apart from its fundamental interest, the information is required for such applications as shielding calculations, the interpretation of radioactivity observed in reactor core components and activation analysis.

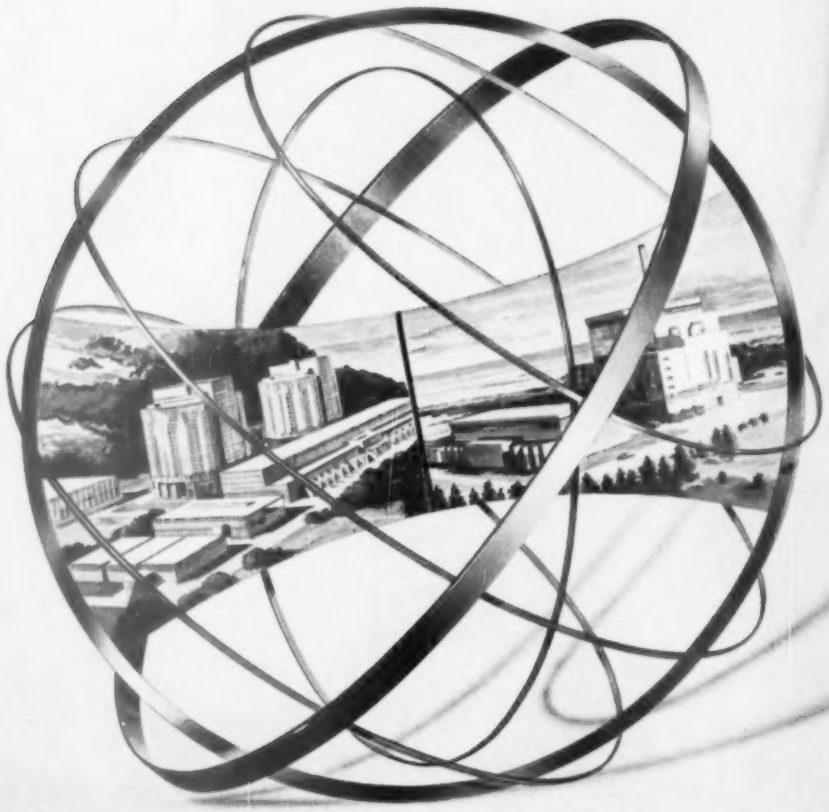
H. A. Tewes (LRL) reported a large number of cross-section measurements

G.E.C.
AND SIMON-CARVES LTD
ATOMIC ENERGY GROUP

on both sides of the world

Seventy miles from Tokyo, at Tokai-Mura, The General Electric Company Limited of England and Simon-Carves Limited are building Japan's first full-scale earthquake-proof nuclear power station. When completed in 1965, this will represent a triumph for nuclear engineering. On the opposite side of the world, at Hunterston, G.E.C. and Simon-Carves are building one of the world's largest nuclear power stations to provide electricity for the south of Scotland.

The combination of G.E.C. and Simon-Carves Limited makes available prodigious resources for atomic power development. As one of the largest electrical and mechanical engineering Companies in the world, G.E.C. itself employs over 70,000 people. Simon-Carves Limited are one of the leading British specialists in large steam-raising plant, coal cleaning and carbonising plant, and in chemical and civil engineering. The Group is able to design, build and install nuclear power stations anywhere in the world, to suit local conditions.



HEADQUARTERS: THE GENERAL ELECTRIC COMPANY LIMITED OF ENGLAND ERITH KENT

This article starts on page 132

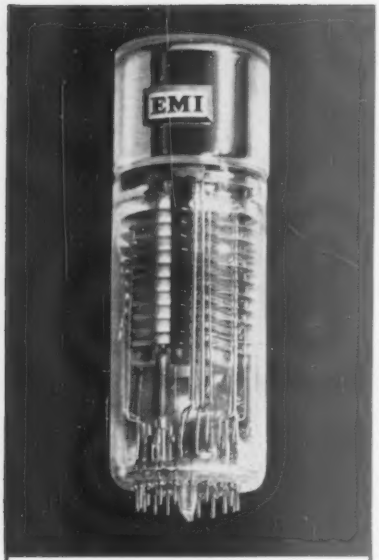
made with targets throughout the periodic table and neutrons in the energy range 8.3–15 Mev. The results were compared with predictions based on "compound nucleus" and "direct interaction" models. For $(n,2n)$ reactions, the agreement with compound nucleus theory is good. The accord between theory and experiment as far as (n,p) and (n,α) reactions are concerned is less satisfactory. Livermore results confirm and extend earlier data showing that these cross sections are larger than expected from compound nucleus considerations and suggest that direct interactions are important.

A closely related paper was given by J. P. Butler (AECL), who described the variation of the $(n,2n)$ reaction cross section of Th^{232} with neutron energy. These results were more detailed than those presented by Tewes but where comparison was possible the agreement was satisfactory.

A. P. Baerg (NRC) has observed that the (n,H^3) reaction cross sections for 14-Mev neutrons and target elements of intermediate atomic number are smaller than the cross sections of the (n,He^3) reactions. This, he suggests, is because in the (n,He^3) reactions the incoming neutron "picks up" two protons, usually from the same nuclear shell, whereas the neutron and proton "picked up" in the (n,H^3) reaction are frequently in different energy states and therefore the reaction is less probable. When the neutron and proton can be taken from the same nuclear shell, as they are in N^{14} and S^{32} targets, the (n,H^3) reactions have sizeable cross sections.

G. R. Martin (DU) described experiments performed to determine the absolute cross section of the Al^{27} $(n,\alpha)Na^{24}$ reaction with 14-Mev neutrons so that this reaction could be used as a standard in the measurement of nuclear-reaction cross sections. The method is based on the measurement of the small quantity of He^4 produced. Although this amounts to only 10^{-7} cm^3, the yield and hence the cross section can be measured with an accuracy of about 1%. The result obtained was 116 mb but further experiments will be required before a final value is given. The 14-Mev neutron cross sections for a number of other elements relative to Al^{27} (n,α) were also reported.

The cross sections of three thermal-



A New Multiplier Phototube for High Temperature Operation

Type 9607B. This 2" diam. soda glass tube has been designed to work over a wide range of temperatures with very low dark current, making it suitable for such applications as bore hole logging. It can operate quite happily at 150° Centigrade. The end window semi-transparent photocathode is of the multi-alkali type, and the 11-stage Venetian blind dynodes are coated with Ag Mg 0 secondary emitting material.

TYPICAL CHARACTERISTICS

Overall sensitivity.	25 A/L at 3000 volts.
Dark current at 150° C.	5 x 10^{-9} A approx.
Cathode diam.	44 mm. min.
Bulb diam.	51.5 mm. max.
Overall length.	155 mm. max.

EMI ELECTRONICS LTD
VALVE DIVISION
HAYES · MIDDLESEX · ENGLAND

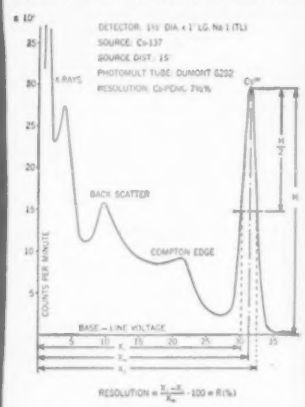
Distributors in U.S.
Hoffman Electron Tube Corporation
804 Salisbury Park Drive
Westbury L.I. New York
Tel: EDgewood 3-6650

EMI

EE154

Sodium Iodide (Tl) Crystals now available with a GUARANTEED RESOLUTION

TYPICAL GAMMA RAY SPECTRUM



Scintex Brand Crystals are unconditionally guaranteed for one year under normal usage.

CRYSTALS DIVISION
ISOTOPES, INC.
123 Woodland Avenue, Westwood, New Jersey

VAPOR BLAST Liquid Honing*

Superior Finishing Method for Missile Production

Proven highly profitable and acceptable in applications like:

- Deburring holes and ports in Servo valve mechanisms.
- Cleaning Printed Circuitry prior to solder dip operations.
- Deburring small complex configuration Inertial Guidance parts.
- Preparing Nose Cone and other shapes for plating.
- Heat Treat Scale removal without destroying size tolerance on precision parts.
- Cleaning Metals fused to Glass without destroying Glass.

YOU, too, may profit by VAPOR BLAST LIQUID HONING on these and many other applications in your field. Write for details and engineering aid on your specific problem — or send a sample for free processing.

VAPOR V·B BLAST
MILWAUKEE WISCONSIN

VAPOR BLAST MFG. CO.
3113 WEST ATKINSON AVENUE
MILWAUKEE 16, WISCONSIN

neutron reactions involving gaseous targets, O^{17}, Ar^{36} and N^{14}, were reported by D. B. Primeau (AECL). The method consisted of adding the gas under study to the filling of a gridded ionization chamber and counting the α-particles or protons emitted when the chamber was exposed to a thermal-neutron beam. The beam intensity was measured with a fission chamber which, in turn, was calibrated by gold activation. The results relative to a 2,200 meters/sec activation cross section of 98.8 barns for gold are O^{17} (n,α): 0.236 ± 0.002 b; $Ar^{36}(n,\alpha)$: 5.56 ± 0.03 mb; and $N^{14}(n,p)$: 1.84 ± 0.02 b. All three reaction cross sections show a $1/v$ behavior within the limits of error in epithermal-neutron irradiations.

R. F. Coleman (AWRE) described research using 37.5-Mev O^{16} ions. The cross section for the radiative capture of O^{16} by Al was found to be 0.2 μb, a value about one-tenth that expected from theory based on the compound-nucleus model. Because the cross section of reactions of this type is small, the need for very pure targets was emphasized by Coleman. Radiochemical measurements of the cross sections of transfer reactions were also reported, and the results indicate that the transfer of a proton from Al in the reaction Al^{27} (O^{16}, F^{17}) Mg^{26}, for example, is more probable than the transfer of a neutron from O^{16} in the reaction Al^{27} (O^{16}, O^{15}) Al^{28}.

Reprints Available

Nuclear Energy In Space

(Pages 53-100 of this issue)
Price $1.25

Reprint Department

NUCLEONICS

330 West 42nd Street
New York 36, New York

PURITY as high as 99.9975% with 'LINDE' RARE GASES

MONATOMIC
DIATOMIC
RADIOACTIVE
SPECIAL MIXTURES
COMBINATIONS

All LINDE atmospheric gases are produced under continuous Mass Spectrometer Control—offering the *highest possible purity* for nuclear processes.

Huge production facilities and a widespread distribution system make it possible for LINDE to supply large quantities of these gases and mixtures throughout the country—in bulbs, cylinders, or liquids via trucks. These unique capabilities are the result of 50 years of pioneering research and development work in rare gases and their behavior.

LINDE gases serve as refrigerants, aid in radiation detection, and effectively shield materials and equipment. In reactor assemblies, they serve as purge gases, assist in heat transfer and fuel element processing, and protect EBR-type reactor piles. In instrumentation they are used as fill-gases, insulation for high-voltage terminals, and in gaseous scintillation counters and radiation intensity measuring devices.

For complete data on gases, write for a copy of F-1002C, *"Linde High Purity Gases."* Address Dept. NU-09, Linde Company, Division of Union Carbide Corporation, 270 Park Avenue, New York 17, N. Y. *In Canada:* Linde Company, Division of Union Carbide Canada Limited, Montreal 7.

LINDE COMPANY
UNION CARBIDE

LINDE and UNION CARBIDE are registered trade-marks.

Dajac LABORATORIES

SCINTILLATORS

- Polyphors®— polystyrene or polyvinyl toluene
- Loaded liquid Scintillators
- PYP-1* and standard waveshifters
- Scintillation grade fluors
- Available in all sizes and shapes up to 5′ x 5′ x 1′

*Patent Pending

Write for Data Sheet today.

THE Borden CHEMICAL COMPANY
5000 LANGDON STREET • P. O. BOX 9523
PHILADELPHIA 24, PA

"You've certainly grown in stature, Chief, since becoming a NUCLEONICS WEEK subscriber."

— RBM, Ankara

Make a date this week with . . .

NUCLEONICS WEEK 330 WEST 42nd ST., NEW YORK 36, N.Y.

NUCLEAR BOOKSHELF

COMING NEXT MONTH—A 10-page Spring Roundup of nuclear books—including reviews of new nuclear books, articles on nuclear literature and publishers' lists of new books.

BOOKS RECEIVED

Materials in Nuclear Applications (American Society for Testing Materials, Philadelphia, Pa., 1960, vi + 344, $8.25). Papers presented at three symposia, "Radiation Effects and Dosimetry," "Postirradiation Effects in Polymers" and "Ceramics in Nuclear Energy," are included in this volume. In addition the book contains two papers on Industrial Water for Reactor Use. These papers serve as an excellent broad coverage of the work being done in these respective fields.

Theoretical Physics in the Twentieth Century, edited by M. Fierz and V. F. Weisskopf (Interscience Publishers, Inc., New York, 1960, ix + 328 pages, $10). This book, which was originally intended to celebrate Pauli's 60th birthday and then became a memorial volume at his untimely death, contains articles that summarize briefly the progress in fields of theoretical physics that were closest to Pauli's heart. The articles that have been included discuss work done during the 1930's in developing the basic ideas of quantum mechanics. Since each of the chapters in the volume is written by an outstanding scientist in the field, the book is not only fascinating reading, but is also a fine glimpse into the history and development of quantum theory.

Proceedings of the American Power Conference, Vol. 12 (Illinois Institute of Technology, Chicago, Ill., 1960, xxxi + 869 pages, $10). Among the fields covered at the Power Conference in March 1960 and included in this volume are mechanical, electrical, hydroelectrical and water power as well as nuclear power. The nuclear-power sessions include papers on the Dresden station, economics of nuclear power and various aspects of power reactors.

Semiconductor Abstracts, Vol. 6, compiled by Battelle Memorial Institute (John Wiley & Sons., Inc, New York, 1961, 528 pages, $14). This volume contains 1,933 abstracts of articles published here and abroad during 1958 on semiconductors; included are abstracts of 10 papers on semi-conductor applications to radiation detectors.

Foundry Radiation Protection Manual (American Foundrymen's Society, Inc., Des Plaines, Ill., 1960, iii + 60 pages, $9). Important aspects of radiation in the foundry such as its nature and sources, health, control, radiation detection, protection and safe handling are dealt with in simple terms in this book. The last chapter contains a glossary of radiation terms. The book should be of interest to the foundryman who does not have a nuclear background, but wants to become acquainted with nuclear technology.

ALSO of NOTE

Directory of Nuclear Reactors, Vol. 3. This new IAEA book lists information on 96 research, test and experimental reactors in operation or under construction in 21 countries. The reactors covered are: 27 light-water moderated pool, 6 liquid homogeneous, 19 solid homogeneous, 13 heavy-water moderated, 4 graphite moderated and 6 fast research reactors. In each category, one representative reactor is discussed in full detail; general information and major modifications are listed for the remaining reactors. 354 pages, $4. *IAEA, Vienna or International Publications, Inc., 801 Third Ave., New York 22, N. Y.*

Atoms for Industry, World Survey discusses briefly such nuclear subjects as world programs and international cooperation, economics and financing, reactors and reactor safety, fuel, marine propulsion, isotopes and radiation. The booklet also describes the activities of governmental atomic agencies throughout the world. 160 pages, $3. *Atomic Industrial Forum or International Publications, Inc., 801 Third Ave., New York 22, N. Y.*

AECL Radioisotope Handbook contains a variety of introductory and

technical information on radiation, fission and reactors, radioisotope production and uses, shielding and information on Co^{60}. Appendices list conversion factors, properties of radioisotopes, lists of elements and products and services. 64 pages. *Atomic Energy of Canada Ltd., P. O. Box 93, Ottawa, Canada.*

Recent Research on Controlled Thermonuclear Fusion, IAEA Review Series, No. 4 includes the work of C. M. Van Atta at Lawrence Radiation Laboratory using magnetic mirror confinement and the Astron device, R. G. Mills at the Princeton stellarator and A. H. Snell with the DCX experiment at Oak Ridge National Laboratory. 80 pages, $1. *IAEA, Vienna, Austria or International Publications, Inc., 801 Third Ave., New York 22, N. Y.*

Mass Spectrometry for Uranium Isotopic Measurements, IAEA Review Series, No. 5 describes instruments and techniques for preparing samples and standards and for calibrating standards as well as analytical procedures for mass spectrometry. 47 pages, $1. *IAEA, Vienna, Austria or International Publications, Inc., 801 Third Ave., New York 22, N. Y.*

Radioisotope Measurement in Nuclear Medicine, by Frank H. Low, discusses in simple terms what radioactivity is and how it can be measured and used for medicine. *Picker X-ray Corp., 75 Varick St., New York, N. Y.*

Large Radiation Sources in Industry, Vol. 2 contains the proceedings of the Warsaw Conference (Sept. 8–12, 1959). The volume contains papers on Radiation and Chemical Reactions, Special Applications of Radiation, Radiation in Food Preservation and Economics of Radiation Processing. 447 pages, $4.50. *IAEA, Vienna, Austria or International Publications, Inc., 801 Third Ave., New York 22, N. Y.*

Metrology of Radionuclides contains the proceedings of the symposium held in October, 1959 on metrology of radionuclides—the precise measurement of the absolute value of radioactive-source activity. The papers give a survey of routine standardization methods of radionuclides as well as new developments in absolute measuring methods for standardization. 472 pages, $5. *IAEA, Vienna, Austria or International Publications, Inc., 801 Third Ave., New York 22, N. Y.*

7-C-12 Evaporator system, 360 liter/sec. capacity; available with glass or metal chamber

Ultek ELECTRONIC high-vacuum SYSTEMS

clean vacuum—no fluids, no contaminants

high vacuum—10^{-5} through 10^{-9} mm Hg and below, chamber volumes from 0.001 to 100 cubic feet

low-cost operation — UlteVac ionic pumps need minimum maintenance, operate unattended for months

System completely self-contained and movable

No water lines or plumbing connections

Requires only an AC outlet

high-vacuum applications . . .

- vacuum tube processing
- thin film deposition
- space simulation
- environmental testing
- general physics research

complete vacuum line . . .

- standard and custom systems, with pumps from 5 to 2000 liters/sec.
- sorption roughing pumps
- metal-sealed fittings
- high-vacuum valves
- ambient foreline traps
- vacuum chamber feed-throughs and view ports

Write Today —

FREE Reprint of technical article, "Ionic Vacuum Pumps," by Dr. Lewis D. Hall

ULTEK CORP.

920-N Commercial St.-Palo Alto, Calif.-DA 1-4117

ULTEK SALES ENGINEERING OFFICES: BOSTON · CLEVELAND · PHILADELPHIA

Ultek vacuum station designed for experimental tube processing

Suppliers to Project Rover—Nuclear Energy in Space

Project Rover (see p. 77, this issue) is concerned with the development of reactors and related nuclear technology for space vehicle propulsion. The program is administered by the joint AEC-NASA Nuclear Propulsion Office under the technical direction of Los Alamos Scientific Laboratory. The experimental reactors are called Kiwi.

The table below lists the major contractors to NPO for Project Rover and describes the contract(s) of each. The table on page 142 lists some suppliers of more than $2,000 worth of products to Edgerton, Germeshausen and Grier who provided the data transmission and recording system for the Kiwi-A reactor tests.

Major Contractors for Project Rover

Contractor	*Description*
ACF Industries, Inc. South Albuquerque Works	Reactor mechanical design; design and fabrication of pressure shells, special tooling and handling equipment, test car, prime mover and control system; assembly and disassembly of reactors
Aerojet-General Corp. Aetron Division	Test Cell "D" design
Aerojet-General Corp.	Analysis and testing to predict, from steady-state data, dynamic characteristics of model topping-cycle turbopump system using liquid nitrogen as working fluid
Air Products, Inc.	Engineering services for Test Cell "C" and cryogenic modifications to Test Cell "A" at Nevada Test Site
Battelle Memorial Institute	Study of tensile properties of aluminum alloys between room temperature and − 423° F
Bendix Corporation	Develop and furnish experimental linear pneumatic-positional servo-mechanism for Kiwi-B control-rod drive
Brush Beryllium Co.	Fabricate rods, forms, etc.
Burns & McDonnell	Architect-engineering services
Chance-Vought Corp.	Preliminary study of end-of-mission and accidental disposal of ROVER, PLUTO, SNAP and manned aircraft reactors in sea
Convair Corp.	Design flight-test systems, formulate development program for flight test, determine cost and safety requirements
Douglas Aircraft Co.	Design flight-test systems, formulate development program for flight test, determine cost and safety requirements
Edgerton, Germeshausen & Grier	Perform direct-field support of Kiwi-A tests including installation and operation of data transmission and recording system; as well as data reduction and report preparation
Lockheed Aircraft Co. Georgia Division	Four year experimental study of engineering properties of materials under low-temperature-radiation operating conditions of nuclear reactors; design flight-test systems, formulate development program for flight test, determine cost and safety requirements
The Martin Co. Baltimore, Maryland	Six month study to find possible hazards associated with nuclear rockets; design flight-test systems, formulate development program for flight test, determine cost and safety requirements
National Bureau of Standards	Develop instrumentation to measure hydrogen conditions in nuclear rocket to sense and feed data into automatic control system of nuclear rocket; evaluate unknown properties of hydrogen
Nuclear Development Corp. of America	Develop methods of calculating shield performance
Ralph M. Parsons Co.	Six-month study of requirements for national nuclear-rocket test facility
Reynolds Electrical & Engineering Co., Inc.	Construction services, radiological safety services, maintenance and operational support for facilities at Nevada Test Site
Rocketdyne Division North American Aviation, Inc.	Design and fabricate liquid-hydrogen-cooled noozle; analyze alternate designs of nozzle systems; design and develop high-capacity liquid-hydrogen pumping system
Technical Research Group, Inc.	Devise new shield concepts and new methods of calculating shield performance. Establish shielding requirements for radiation-sensitive equipment
Univ. of California Los Alamos Scientific Laboratory	Reactor-core design; development of fuel-element materials and structural materials; systems analysis; reactor engineering and testing; general consulting on Rover

AMF REACTORS in planning, construction or operation:
Columbus, Ohio
Munich, Germany
Plainsboro, New Jersey
Hamilton, Ontario
Turin, Italy
Sterling Forest, New York
Athens, Greece
Lisbon, Portugal
Rehovoth, Israel
Teheran, Iran
Mayaguez, Puerto Rico
Buffalo, New York
Istanbul, Turkey
Rawalpindi, Pakistan
Tokai-Mura, Japan
Ames, Iowa
Delft, Netherlands
Gainesville, Florida
Seattle, Washington
Los Angeles, California
Vienna, Austria

"Biz AMF i seçtik"
「私達はAMFを選んだ」
"Wij geven de voorkeur aan AMF"
"Nos escolhemos AMF"
"Wir haben AMF gewählt"
Ἐξελέξαμεν τὴν A.M.F.
"Hemos escogido AMF"
"Abbiamo scelto AMF"
"We chose AMF"

This decision has been made 21 times and in 12 languages by representatives of universities, atomic energy commissions and research institutes charged with the selection of the best research or training reactor for their needs. While the claim of leadership based on quantity of output is often a hollow boast, *in reactor technology and construction it has extraordinary significance.*

Each new reactor or modification has explored unknown areas of performance and manufacture. Experience gained in shrinking these areas literally cannot be duplicated. To *your* needs AMF brings unique knowledge covering design, development, fabrication, engineering-construction and start-up of pool, heavy and light-water tank, and special purpose reactors.

AMF's record starts with the Battelle Memorial Institute's pool-type reactor, in operation since 1956, the pioneering effort in research reactor standardization. The roster of AMF design and fabrication innovations, all of them developed to meet special customer needs, is unmatched.

AMF Atomics across the board

AMF Atomics has utilized AMF's vast mechanical experience in production of a wide range of reactor components and auxiliary equipment including:

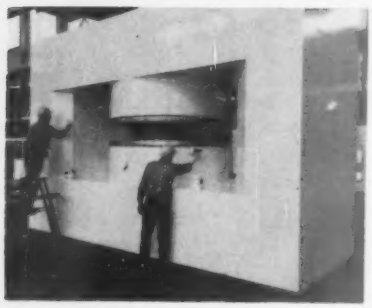
- ***Reactor servicing equipment***
- ***Control rod drive assemblies***
- ***Standard and heavy-duty manipulators***

AMF ATOMICS
A Division of
American Machine & Foundry Company
261 Madison Avenue, New York 16, N.Y.

AMF Experience, performance across the board . . . across the world

Suppliers for Edgerton, Germeshausen and Grier on Kiwi-A Reactor Test

Supplier	*Articles*	*Supplier*	*Articles*
Adage, Inc.	convertor, volt meter	Kin-tel Div. of Cohn Electrics	amplifiers
AMP, Inc.	patch boards	Kooltronic Fan Co.	blower fans
Ampex Corp.	tape recording systems	Magnecraft Elec. Co.	enclosures
Amphenol Connector Div.	connectors	Mallory Battery Co.	batteries
Ansonia Wire and Cable Co.	cable	Mechanical Products Corp.	circuit breakers
Assembly Products, Inc.	meter relays	Metal Bellows Corp.	trans. calibrating rigs
Barber-Coleman Co.	micro positioners	Minneapolis Honeywell Regulator Co.	switches
Bendix Pacific	computers	National Semiconductor Prod. Div. Hoffman Electronics	semiconductors
William Brand and Co., Inc.	cable	Offner Electronics Inc.	amplifiers, choppers
Cardinal Instru. Corp.	thermocouple	Packard Bell Electronics Corp.	digital convertor
Christie Electric Corp.	power supplies	Perkins Engineering Corp.	power-supply instruments
Churchill Lighting Corp.	sheet metal	Phelps Dodge Copper Products Corp.	burial cable
Clare, C. P.	relays	George A. Philbrick Researches	amplifiers
Consolidated E. D.	electromanometer	Pump Equipment	solenoid valves
Di/An Controls	shift registor assembly	Radio Shack	trimpots
Diebold, Inc.	microfilm camera	Rex Corp.	cable
Duncan Electric Co.	potentiometers	Sager	switches
Dynamics Instrumentation	amplifiers	Sanborn Co.	recorder assembly, spare parts, recording system
Electro Switch Corp.	switch	Skinner Chuck Co.	valves
Eltron Engineer Co.	potentiometers	Stromberg-Carlson Co.	relays
Emcor	console rocks	Tele-Dynamics, Inc.	demultiplexing equipment
Epsco, Inc.	voltage standard, secondary voltage source	Tensolite Insulated Wire Co.	cable
Falstrom Co.	100 EG & G cabinets	Times Wire and Cable Co., Inc.	cable
General Devices Co.	4-communicating assembly, oscillators	Unimex Switch Div., W. L. Maxson Corp.	switch
Handley Elec.	potentiometers	Vector Mfg.	oscillators
Hertner Electric Co.	motor alternate units	Geo. H. Wahmann Manuf. Co.	Buchanan terminal blocks
Hewlett Packard Co.	recorder	Western Devices	panel racks
Insul-Tab	wire tabs		
International Instruments, Inc.	meters		
Kepco Laboratories	power supply instruments		



15–40 Mev Cyclotron

310-ton cyclotron, delivered by the Bethlehem Steel Co. to the University of Michigan, should go into operation in 1963. Cyclotron core has half-inch air gap between pole and pole tip in magnetic core. Thus emerging particles can be focused better and particle energies can be greater.—Bethlehem Steel Co., Bethlehem, Pa.

Low-Energy Survey Meter

This portable survey meter with five full-scale sensitivity ranges of 0–3, 0–10, 0–30, 0–100 and 0–300 mr/hr measures beta and gamma radiation over a broad energy range. Meter has a 10% accuracy with gamma-energy dependence of ±15% from 6.5 kev to 1.2 Mev.—Victoreen Instrument Co., 5806 Hough Ave., Cleveland 3, Ohio.

Vibrator for Nuclear Fuel

Variable Impact Vibrator (VIV), which weighs only 38 lb, develops over 2,000 g variable impact and a variable frequency range of 0–500. Because of the new design, air supply is no longer a major problem. VIV has been used at Combustion Engineering to compact ceramics and metals in nuclear fuel work.—Branford Co., 132 Glen St., New Britain, Conn.

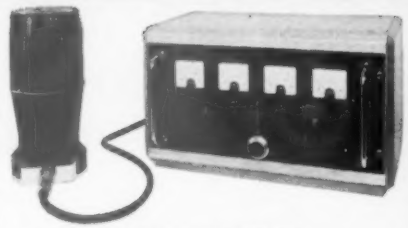
Liquid Scintillator Concentrate

Liquifluor, a pre-mixed, 25 times concentrate of PPO and POPOP in purified toluene, eliminates weighing, stirring and mixing time in the laboratory and reduces the chance of error from these operations. Liquifluor can be added to any liquid scintillator system containing toluene. Each liter of concentrate contains 100-gm PPO and 1.25-gm POPOP. Liquifluor comes in 1-liter and 500-milliliter bottles.—Pilot Chemicals, Inc., 36 Pleasant St., Watertown 72, Mass.

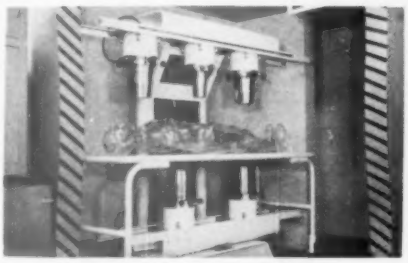
Welding and Brazing Alloys

Aluminum welding and brazing alloys 718, 1100 and 4043 now come with "nuclear grade" certification; thus they can be used for reactors and radiochemistry.—All-State Welding Alloys Co., Inc., White Plains, N. Y.

FOR THE NUCLEAR SCIENTIST



Environmental Monitor



Human Body Radiation Monitor

INSTRUMENTS

NE 8421 Radio-Iodine Environmental Monitor (I^{131}), fully transistorized and suitable for vehicle borne monitoring and safety surveys on other health physics problems (as with Plutonium). The enhanced differential reading allows quantitative measurement of Radio Iodine^{133} even in the presence of strong competing gamma radiation from other iodine activities.

NE 8105 Lean/Fat Radio Equipment on Live Animals or carcasses determines K^{40} in lean meat or Cs^{137} fall out contamination separately. Installed at Department of Agriculture, Bethesda, Maryland.

NE 8102B Human Body Radiation Monitor permits detection of a 3 x 10^{-9}C body burden of Ra^{226} in a steel room. One of several designs installed in Australia, Canada, Great Britain and Germany.

UNIVERSAL RADIATION DETECTORS SHIELDED ROOMS PHANTOMS

SCINTILLATORS

NE 102—This outstanding plastic scintillator is available in any size or shape. *Slab units* for accelerator and Cosmic Ray Studies, *Thin Sheet* for beta particle counting, *Phosphor Well Counters*, *Continuous Capillary Flow Counters* for efficient reproducible counting of alphas and betas in gaseous, aqueous or alcoholic solutions. Fine *Filaments* for (1) Solid Scintillation Chambers for recording nuclear tracks, (2) Directional Neutron Detectors, (3) Tracer counting of aqueous solutions, (4) Image Intensifying Bundles.

NE 400, NE 401, NE 402 Thermal Neutron Detectors providing excellent discrimination against gamma rays (Bulletin 13).

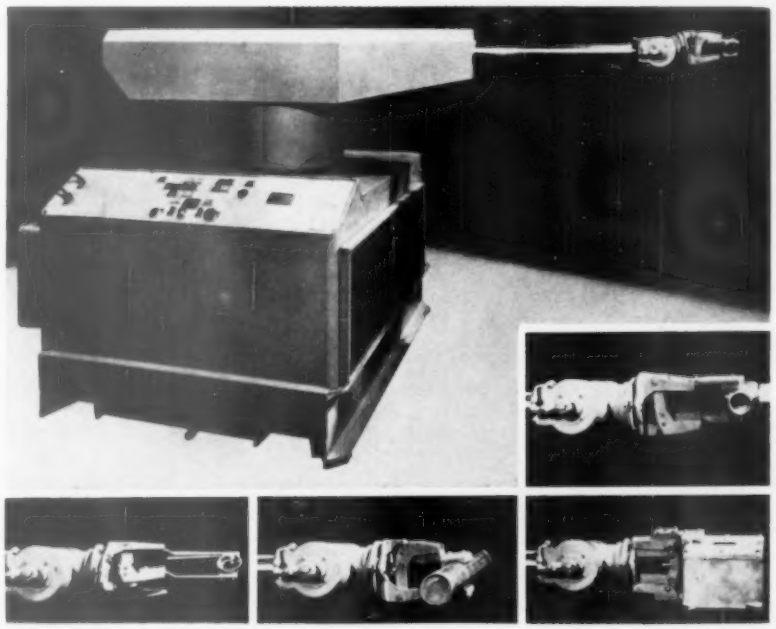
NE 404—Fast Neutron Detectors based on photon recoil detection—all units complete with reflectors.

NE 450—Fast Neutron Hornyak Button type with ZnS(Ag) dispersed in transparent plastic medium in optimum proportions (Bulletin 15).

NEW PLANT

550 BERRY STREET
WINNIPEG 21, CANADA
Assoc: N.E. (G.B.) Ltd., Edinburgh

NUCLEAR ENTERPRISES LTD.



Robot with a Memory

Unimate, a robot that can take over repetitive jobs now performed by men, may prove useful in hot cells and around reactors. The Unimate remembers 200 sequential commands and directs its arm to act according to the stored information in its brain. By simply being led through the motions of a job once, Unimate learns a task on the job. It then repeats the operation continuously until a new routine is taught to it. For different jobs a variety of hands or hand tools can be fitted on the arm. The arm telescopes in length from 3–7 ft; it sweeps over an arc of 220 deg horizontally and 60 deg vertically. It can, therefore, reach from within 4 in. of the floor to 90 in. above it. In this span of reach it handles up to 75-lb objects faster than a human can. To store the directions for any particular job, the memory drum has a capacity of 16,000 bits of information. These commands are stored in 200 rows of 80 bits of information around the circumference of the drum; each row corresponds to a distinct movement that the Unimate can remember.

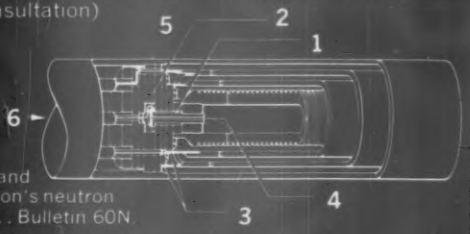
Tiny Motors for Nuclear Work

Model 36V58RP138 reversible motor acts as a safety-rod drive for reactors. The tiny 14-oz motor, which measures $1\frac{1}{2} \times 2\frac{3}{4}$ in., has an input of 115 volts, 3 phase, 400 cycles. Output is 20 oz-in. torque at 333 rpm continuous duty. Motor operates for 1,000 hr in water-saturated helium gas at ambient tem-

WHY ANTON NEUTRON CHAMBERS CAN STAND UP TO HEAT, VIBRATION AND SHOCK

You can—now—integrate the latest Anton ionization and fission chamber developments into your reactor instrumentation. Operation to 300°C is available. Anton chambers meet requirements of Mil-Std-167 and Mil-S-901 for vibration and shock.

1—and 2—Anton UNIT-MOUNT* fixes the chamber elements rigidly between high temperature ceramics. The self aligning UNIT-MOUNT prevents any movement of precisely positioned concentric elements with respect to each other. 3—Exact electrode spacing maintained by precision ground ceramic spacers. 4—An unobstructed exhaust port is provided. 5—2-S Aluminum outer envelope. 6—Connector end not shown, but a variety of connectors (watertight, welded, hermetic, etc., available upon consultation)



Write for free design facts and operational data about Anton's neutron chambers and detectors . . . Bulletin 60N

ANTON ELECTRONIC LABORATORIES INC.
1226 Flushing Ave., B'klyn 37, N.Y.

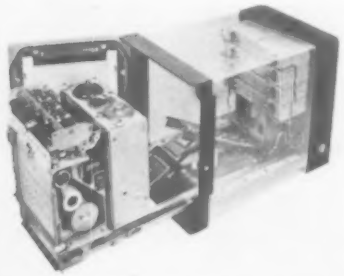
*Reg. app. for.

Products and Materials

Department starts on page 140

peratures of 50–95° C.

Model 32U21RP141 has input of 110 volts, single phase, 60 cycles and output of 28 oz-in. torque at 20 rpm. The 4-lb 11-oz motor measures 3.31 × 5.5 in. It operates at ambient temperatures of 100° C continuously for 500 hr or has an unattended life of 1 yr. The motor resists radiation doses of 2×10^9 roentgens of gamma rays or 5×10^{16} neutrons/cm².—Electro Products Division, Western Gear Corp., 132 W. Colorado Blvd., Pasadena, Calif.



Potentiometer Without Slidewire

Electronik 17 (above), comes with circular or strip charts or circular scale indicator which can be quickly interchanged. The designers of the potentiometer have eliminated the conventional slidewire rebalancing unit. Instead a Stranducer is used; this works on the principle that a wire when stretched changes its resistance in proportion to its elongation. Four looped-wire strands are electrically arranged to form variable-resistance legs of a Wheatstone bridge; as tension is applied, they vary in position. Other features of potentiometer include a new measuring circuit, stray-signal rejections, one reference-junction compensation for all thermocouples and servicing without interrupting operation.—Minneapolis-Honeywell Regulator Co., Brown Instruments Division, Wayne and Windrim Ave., Philadelphia 44, Pa.

Pulse-Height Analyzer

Model 52-26 contains an external magnetic tape storage and allows re-entry of digitalized data into the analyzer memory. External data processing is also added by a series of multiplier switches that multiply 0.1, 1, 10 or 100% with no variation in channel number. Data are transferred from the

A MAJOR ADVANCEMENT IN
CERMET FABRICATION TECHNOLOGY

COATED PARTICLES & PARTS BY

NUMEC®

COMMERCIALLY AVAILABLE FROM NUMEC—A LARGE NUMBER OF METALLIC AND NON-METALLIC coatings on base materials.

TYPICAL COATING MATERIALS—	Cu · Ni · Cr · Nb · V · Mo · Si · Be · W · C (pyrolytic) · BeO · SiO_2 · Al_2O_3 · (Duplex coatings also available)
TYPICAL BASE MATERIALS—	UO_2 · UC · U metal · ThO_2 · WC · BeO · SiO_2 · C · glass · steels · alloys · semi-conductors · carbides · refractory metals · graphite ·

NUMEC coatings can be applied to base materials including fine powders, spheres, pellets, tubing, plates, sheet, and other more complex configurations. For information on coated particles, nuclear materials or special service contact:

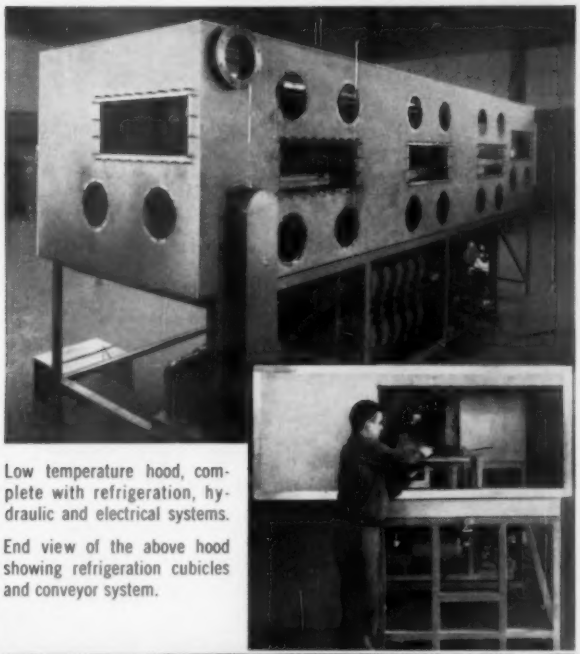
NUMEC
Nuclear Materials & Equipment Corporation
Apollo, Pa.

Phone: GRover 2-8411

Cable: NUMEC TWX: APO-276

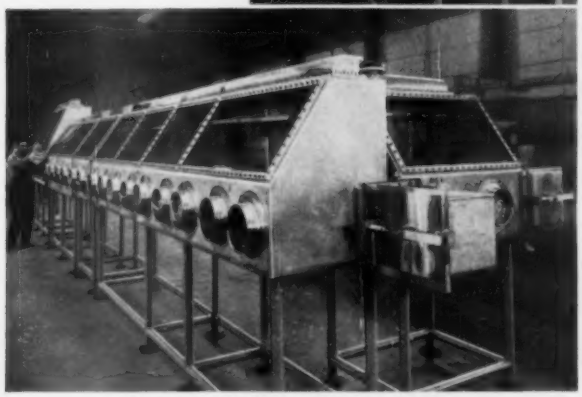
NUMEC's growth is constantly creating new and challenging opportunities for scientists and engineers in basis research and development. Write today for information.

Krueger
Craftsmanship
In Stainless Steel Fabrication



Low temperature hood, complete with refrigeration, hydraulic and electrical systems.

End view of the above hood showing refrigeration cubicles and conveyor system.



Dry box installation for radioactive materials

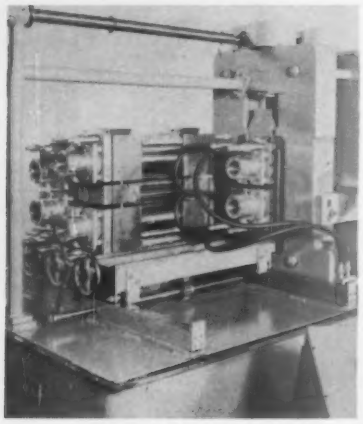
Krueger offers the very finest in custom fabrication of your products in stainless steel. Certified welders using modern welding equipment on .005 to ⅜" thicknesses. Complete product testing. Polished surfaces. Let us estimate your next fabrication requirements. Single items or quantity production.

kfc

Write, wire or phone for information, quotations and references.

Krueger
fabricating co., inc.
west badger road, madison 5, wisconsin

NEWS FROM
LOMA



This heavy-duty, high-precision 2-high/4-high Combination Rolling Mill was recently installed at the new Fuels Technology Center of the Argonne National Laboratory. The outstanding feature of the new machine is its complete enclosure in a controlled atmosphere glovebox to allow the processing of alpha-active, pyrophoric materials, such as plutonium.

To facilitate remote control operation within the glovebox enclosure, the mill is equipped with a mechanized roll changing device comprising a roll storage car, three slideways to carry three roll assemblies, quick-disconnect screwdowns and universal spindle supports. The entire roll assemblies are readily moved into or out of the mill by turning a handwheel and are cross-transferred by moving the car along the face of the mill. Thus, complete roll changes can be performed in a few minutes without undue effort.

The new LOMA rolling mill may be operated in either a 6 in. x 8 in. 2-high set-up or a 1½ in. & 6 in. x 8 in. 4-high set-up. The 2-high arrangement is used for either hot or cold breakdown rolling of plate and sheet, and grooved rolls are also available to process rounds from 1 in. to ¼ in. diameter. In the 4-high set-up strip is cold finish rolled to gauges as thin as .002 in.

The mill is furnished with high-strength steel housings, twin-handwheel wormdrive screwdowns, universal joint spindles, herringbone gearing, and a 15 h.p. reversing variable-speed drive. The roll necks are mounted in super-precision needle roller bearings having a total separating force capacity of 175,000 lb. The bearings are continuously lubricated by an oil circulating system.

Special cartridge heating elements are mounted in the rolls to prevent undue chilling of the materials being hot worked. The heating elements are fed with current through slip rings and brushes mounted at the outboard side of the mill.

LOMA
MACHINE MFG. CO., INC.
114 East 32nd Street
New York 16, N. Y.

analyzer to magnetic tape at 100 decimal digits per sec or 400 channels of 10^5 capacity in <5 sec.—Radiation Instrument Development Laboratory, Inc., 61 E. North Ave., Northlake, Ill.

Portable Vacuum Cleaner

Absolute-filter vacuum cleaner (above) safely collects radioactive and toxic dusts. The heart of the cleaner is a filter that can be easily replaced to control recontamination during filter change-over. Filters have a minimum efficience of 99.97% on particle sizes of 0.3 microns. The collection tank has a recoverable capacity of 1⅔ bushels of dry material. A 1-hp motor powers the unit.—Cambridge Filter Corp., 738 E. Erie Blvd., Syracuse 1, N. Y.

Neutron Diffractor

Diffractor (above), which has variable wavelength, contains a monochromator crystal that rotates in horizontal and

PROPIPETTE
Safety Pipette Filler
holds liquids indefinitely

• Time Tested • No moving parts
• Simple to operate

The new PROPIPETTE eliminates the dangerous practice of using the mouth to draw liquids into pipettes. It is simple to use and the operator soon becomes proficient so that liquids can be delivered quickly, precisely and safely. Measurement precision is extremely high (0.01cc). The instrument has three agate-ball valves which operate independently and the entire procedure can be done with only one hand.

PRICE $7.60 each . . . comes in black, red, green and blue, sent on approval.

all laboratory pipettes can be used with the PROPIPETTE—Safety Pipette Filler.

Write for additional information

INSTRUMENTATION ASSOCIATES
Distributors of Laboratory and Scientific Specialties
17 West 60th Street New York 23, N. Y.

For temperatures from 3000°F to 5500°F you need . . .

Zircoa
REFRACTORIES

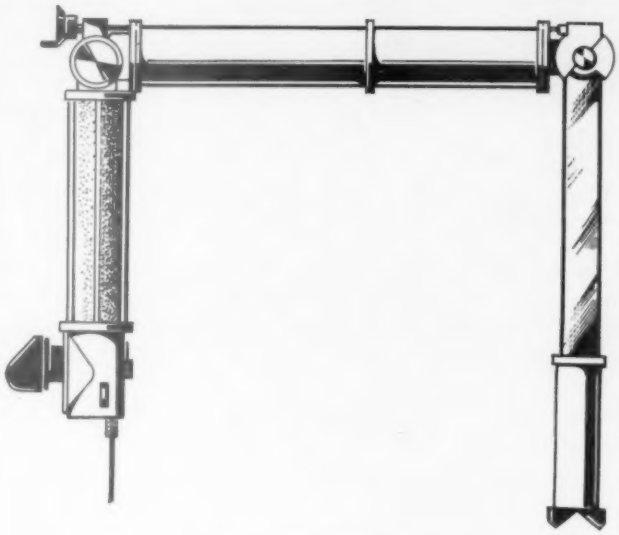
• Made of high purity Zirconium Oxides, rare earth and other refractory metal oxides
• Standard shapes—Crucibles, Brick, Tubes, Plates and other shapes
• Custom shapes—to your specifications
• Heavy duty and laboratory types

Zircoa Refractories are the finest and most dependable you can use. We produce the Zirconium oxides in our own plant, giving us accurate control of every manufacturing step — from raw materials to finished products.

Zircoa Refractories give good service at temperatures from 3000°F to 5500°F in vacuum, inert or oxidizing atmospheres.

GET ALL THE FACTS
Write for Technical Literature and prices.

Zircoa
31501 SOLON ROAD, CLEVELAND 39, OHIO
ZIRCONIUM CORPORATION OF AMERICA



STEREOSCOPIC PERISCOPE SOM

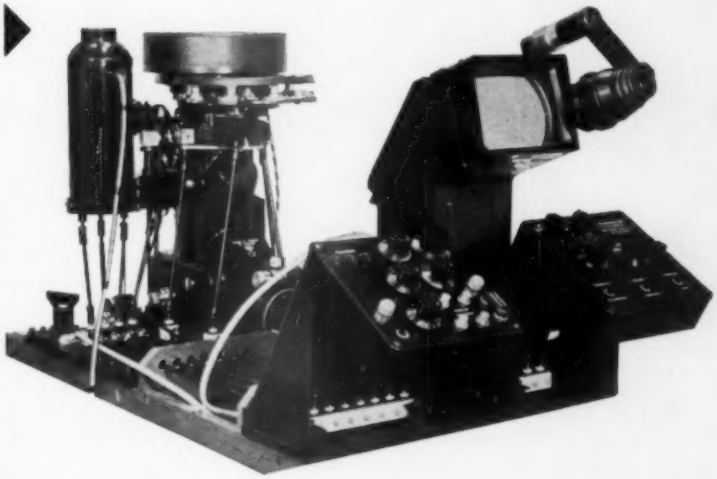
designed to perform remote microscopic examination in nuclear laboratories.

A special device allows to take stereoscopic views.

The lighting system can be located at the end of the periscope. For putting into the working place or taking out of it, the vertical aiming part is easily brought up horizontally by means of a remote-control wheel.

Multiple magnification
of 3.75 to 15
or 7.5 to 30

METALLOGRAPH OPL BRACHET



is composed of:
outside the hot cell:
★ a control panel
★ a block observation
inside the cell:
★ a turret with 8 special objectives of cerium stabilised achromatic or episcopic glasses — with selection switch from the control panel.
★ the objectives are designed in order to be put or removed by a slave manipulator inside the hot cell.
★ a stage with X and Y motion rotating 180° for sample of ø 50 mm.
★ a double pivoting illuminator for observation by normal light (bright or dark field) or by polarized light.
★ a light source from a 200 W. mercury vapour lamp.

The observation on a ground glass screen is a great improvement compared with a single eye-piece and enables vision on a screen by projection.

SAINT-GOBAIN NUCLEAIRE offers for sale specialized equipment for hot laboratories.

SAINT | GOBAIN
nucleaire

23 bd G. Clémenceau-Courbevoie (seine) France

FOR DEPENDABLE PROTECTION
IN CRITICAL OPERATIONS

CHARCO
DRY BOX
GLOVES

PREMIUM QUALITY
MILLED NEOPRENE

FLEXIBLE, FINGER SENSITIVE AND COMFORTABLE

EACH DRY BOX GLOVE IS HIGH VOLTAGE TESTED

CHARCO NEO SOL ®

CHARCO ® RAD BAR

PREMIUM QUALITY, ALL MILLED NEOPRENE. THESE GLOVES ARE OIL, CHEMICAL AND OZONE RESISTANT. THEY CONFORM TO REQUIREMENTS OF ARGONNE NATIONAL LABORATORY SPECIFICATIONS PF-1-b-(Rev. 6).

SEAMLESS, LEAD-LOADED, MILLED NEOPRENE ARE OF A DENSITY OF 3.95 GRAMS PER CUBIC CENTIMETER. UNDER ACTUAL TESTS THESE GLOVES HAVE BEEN PROVEN TO SHIELD OUT SOFT GAMMA RAYS MORE THAN 85%.

WRITE FOR BROCHURE AND TECHNICAL DATA

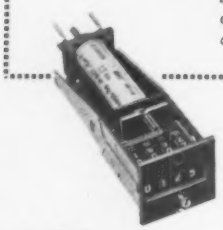
Our Research and Testing Laboratories Welcome The Opportunity To Help Solve Your Problems.

CHARLESTON RUBBER COMPANY

7 STARK INDUSTRIAL PARK — CHARLESTON, SOUTH CAROLINA

You get *MORE* than accurate counting with SODECO Electric Impulse Counters

SODECO just starts with counting accuracy. With SODECO Electric Impulse Counters you get many additional built-in advantages which enable you to use them for your toughest counting problems. For example:



SODECO TYPE TCeZ
Instantaneous Mechanical Reset
• Just flick the toggle Counter resets to zero

SODECO TYPE TCeF
Instantaneous Electrical Reset
• Counter resets electrically-instantly.

• Fast—
counts up to 25 impulses/sec.

• Compact—
only 1.67 sq. in. panel space required for TCeZ4E

• Low power demand—
direct drive from transistor or vacuum tube.

• Long Life—
conservatively rated 100,000,000 count life.

Available with periodical armature, or reset Contacts—Counter provides in-line readout, and does your control job as well.

No matter what your counting problems, you can count on SODECO for the answer. Write for complete information.

LANDIS & GYR, INC. 45 West 45th Street New York 36, N. Y.

Products and Materials

Department starts on page 140

vertical planes and is accessible and interchangeable without removing shielding. With a smallest adjustable rotation step of 5 min of arc, the counter rotates around a specimen within an angular range of $-10 - +120$ deg in the horizontal plane and inclines to angles up to 30 deg.—Maschinenfabrik Augsburg-Nürnberg A. G., Augsburg, West Germany.

Detachable Gloves for Dry Box

A sleeve and glove combination with special detachable collars to which gloves can be attached by a tight-fitting O-ring allows worn-out gloves to be discarded without throwing away the sleeves. Sleeves also contain built-in hand temperature suppressors for constant circulation of fresh air inside gloves.—Wilson Rubber Co., Industrial Division, Canton 6, Ohio.

LITERATURE AVAILABLE

Controlled Atmosphere Chambers. 3 pp.; Delta Design, 7460 Girard, La Jolla, Calif.

Stainless-Steel and Plastic Enclosures with Atmospheric Controls. 2 pp.; Caemco, Inc., Jacksonville 6, Fla.

"S" Gloved Dry Box. Fume Hood. Tool Enclosure. 6 pp.; Royal Research Corp., 11824 Dublin Blvd., Hayward, Calif.

Safety Clothing. 37 pp.; Plasco Safety Products Co., 21 W. Pleasant St., Springfield, Ohio.

Digital Data Systems. 17 pp.; Minneapolis-Honeywell Regulator Co., Beltsville, Md.

3-Inch Portable Oscilloscopes. 15 pp.; Tektronix, Inc., P. O. Box 500, Beaverton, Ore.

Properties of Selected Commercial Glasses. 16 pp.; Corning Glass Works, Corning, N. Y.

Solid-State D-C Power Supplies. 2 pp.; Deltron Inc., 4th & Cambria Sts., Phila. 33, Pa.

All-Purpose Generators, M-G Sets. 2 pp.; Leland Ohio Electric Co., Dayton 1, Ohio

INDUSTRY NOTES

● Oak Ridge National Laboratory reports radioisotope shipments during 1960 totalled 205,675 curies, which were 93,691 curies less than shipped in 1959. ORNL officials explained that less cobalt-60 and cesium-137 has been sold. The number of shipments totaled 12,724 in 1960, 12,950 in 1959.

EXPANSION: **Aerojet-General Nucleonics,** San Ramon, Calif., has purchased 474 acres adjacent to its 11-acre site in conjunction with its present expansion program. The land will be held until further expansion is required. One company spokesman said: "The acquisition reflects the company's confidence in the future of the nuclear industry." Aerojet's present $1-million expansion program, which includes construction of nuclear fuel and manufacturing facilities and laboratories for research—in chemonuclear, nuclear electronics, metallurgy and plasma physics—is nearly completed. . . . **Nuclear Enterprises, Ltd.,** Winnipeg, Canada, has moved into new plant facilities in Winnipeg's St. James area and expanded its Edinburgh, Scotland, subsidiary by 10,000 sq. ft. The company, which makes nuclear instruments, developed a widely used scintillation counter for detection of uranium ore deposits from aircraft, and produces a human whole-body counter and scintillation detection instruments.

NEW BUSINESS: **Union Carbide Corp.** has awarded **General Electric** a $166,200 contract for replacement of 300 fuel elements for the Oak Ridge 30-Mwth Research Reactor (ORR). . . . AEC has licensed **Curtis Nuclear Corp.,** Gardena, Calif., to install radiation sources, calibrate and measure radioactivity of cobalt therapy machines in hospitals and X-ray laboratories in the Western states. . . . A French company, **Société Industrielle du Zirconium,** has been formed by three Germany, Italian and French groups. The firm's headquarters is 195, Faubourg Saint-Monoré, Paris 8. Shareholders, on an equal-share basis, are: Degussa and Metallgesellschaft A.G., Montecatini, and Pechiney. The company will produce zirconium sponge and ingots and conduct research-development for use of the metal in reactors and chemical production. . . . **Associated Nucleonics, Inc.,** Garden City, N. Y., has been awarded the AEC design contract for the U. S. Quartermaster Corps' food irradiation research station to be built at Natick, Mass. The station for the 1-million-curie, cobalt-60 irradiator, designed by Curtiss-Wright Corp., will also have a 24-Mev accelerator designed and built by **Varian Associates,** Calif. August 1962 is the date set for the $1.8-million center to be ready. Associated Nucleonics, among other jobs, assisted in designing the mechanical and electrical components for Yankee Electric Plant. . . . **AMF Atomics,** Canada, Ltd., has shipped 273 natural-uranium fuel elements, valued at about $450,000, to Japan's JRR-3 research reactor at Tokai-Mura.

ACQUISITIONS: **Royal Industries, Inc.,** Los Angeles, exchanging stock 2 for 1, acquired **Dublin Industries, Inc.,** Hayward, Calif. Dublin has an AEC contract for research-development of a 5-watt test model, cesium-137 isotopic power device. At first, Dublin manufactured custom enclosures for handling radiation materials before going into research-development. As Royal's new subsidiary, Dublin will be known as **Royal Research Corp.,** and its staff and facilities will contribute abilities to the parent holding company's Vard div. Vard has a $700,000 Westinghouse contract to supply control-rod mechanisms and other reactor components for use in nuclear submarines. . . . **Technical Measurement Corp.,** North Haven, Conn., is designing a 4,096-channel analyzer for introduction sometime this summer. The announcement was made as TMC unveiled in March its new line of transistorized multichannel analyzers. TMC recently acquired equity in **MicroSemiconductor Corp.,** Culver City, Calif., producers of unusually small semiconductors by a new technique. . . . **Tracerlab, Inc.,** Waltham, Mass., has announced that construction has begun on its new manufacturing facilities in Mechlen, Belgium. Its new subsidiary, **Tracerlab, S.A.,** will participate in European Common Market activities.

FINANCIAL: **Tracerlab, Inc.,** reports 1960 sales of $12,565,692, net profits of $204,493, or 28 cents per share. **High Voltage Engineering Corp.** reports sales of $12,332,849, and earnings of $1,016,650 or $2.26 per share.

ANNOUNCING THE NEWEST SOURCE OF BERYLLIUM METAL

GENERAL ASTROMETALS CORPORATION

Available *now* Beryllium Metal Flake & Powder; Powder Metallurgical Shapes Fabricated in Rod, Tube, Block, Slab, Billet, Sheet and Strip. Also, SUPER-PURITY GRADE Beryllium. (Produced and Marketed under license of Pechiney of France.)

OTHER ASTROMETAL MATERIALS:
High-Density Sealed Graphite; Nuclear Poisons; High-Temperature Refractory & Wear-Resistant Materials ...Carbides, Nitrides, Borides & Silicides.

For information write or call:

GENERAL ASTROMETALS CORP.
320 Yonkers Ave., Yonkers, N. Y., YO 8-2211

Gadolinium, Gadolinium chlori Galactonic acid lactone, Gala loride, G ntaacetat ethanolam allic aci Gallium c lium nit Gallocyanin, Gallophenine, Ga hydrol Gel acid, G de, Ge ethanol isic a acetate, Germyl bromide, Ger Germanium metal, Germanium mo te tra te ap Gi Gitoxigenin, Gitoxin, Gliadin Glucoascorbi d, Glucochlo acid d, Gluc acid, Glucon Glucosaminic , Glucose al Glucose-o-carboxyanilide, Glu Glucose mercap thylme ethylxa oxamin pentaacetate, Glucose sodium Glucose thioureide, Glucose u Glucosides, Glucos pyrid trimethylammonium Gl curonidase, Glucu e, tamic acid, Gluta ut dioxime, Glutara ri anhydride, Gluta hyd reduc d, Glutat ize cami lyceric cero de linium olin cr ic ac Losan

OVER 20,000 CHEMICALS IN STOCK!

Write for Our New 138-Page Catalog!

DELTA CHEMICAL WORKS, Inc.
23 West 60th St. New York 23, N. Y.
Telephone: Plaza 7-6317

Here's How TO GET GAINS UP TO 1,000,000 Z_m, and detect 1 MICRO-MICROWATT DC . . .

WITH

acrostat

LOW-LEVEL MAGNETIC AMPLIFIERS

This brand-new series of ACROSTAT second harmonic magnetic null pre-amplifiers give gains up to 1,000,000 Z_m, with null balances to one micro-microwatt, DC. One microampere of DC control gives one volt of DC output. Operates from 115 volts ± 10%. Ideal for thermocouples, strain gauges, null detectors, meter pre-amplifiers.

For full details, send for Technical Bulletin No. 10

acromag®
INCORPORATED
22515 TELEGRAPH RD. SOUTHFIELD (DETROIT), MICH.
PHONE: ELGIN 7-0030
TWX SOUTHFIELD 970-U

DEL

HIGH VOLTAGE QUALITY RELIABILITY

25 KV-200 MA POWER SUPPLY

- Fully protected
- Fully instrumented
- Self-contained
- Mobile unit
- Input 208 V, 3-phase, 60 cycle
- Reversible polarity
- No exposed high voltage components
- Many other features

Designed and constructed for reliable operation, Model PSC 25-200-2 Power Supply may be used for many research and industrial applications.

Standard Power Supplies and Transformers available from stock. Others can be built to your specific requirements. We also manufacture unusual Regulated Transistorized Power Supplies for High and Low voltages. Write for data.

Model PSC 25-200-2

For further information—write today to Dept. N

DEL ELECTRONICS CORPORATION
521 HOMESTEAD AVENUE • MOUNT VERNON, N. Y. • OWENS 9-2000

Fast Reactor Safety

This article starts on page 114

temperature range for which extrapolations of penetration data (*8*) would predict penetration in ~1 sec. All the Fermi-1 samples show a fuel-alloy escape characteristic of flow under the influence of gravity, in contrast with the EBR-2-type elements whose bond sodium can expel the fuel alloy vigorously under the proper conditions.

In all high-temperature specimens given short power pulses, small longitudinal cracks were observed randomly situated along the cladding surface. Generally, these cracks did not penetrate the cladding. It seemed that the uranium had "dribbled" from the interior exuding through one of these cracks since metallographic inspections, supplemented by positive identification of material composition by "electron microsounding" surveys, disclosed no appreciable attack and dissolution of the zirconium wall of the "threshold" sample.

However, these small cracks were not observed on the elements subjected to the slower heating of constant power transients. Furthermore, the threshold of failure appeared to be about 50–100° C higher than for the short-pulse samples.

Next Phases of Work

During the next several months, the phenomena associated with meltdown in stagnant sodium will be investigated in greater detail. Preparations are being made for the first dry experiments on oxide fuel elements, for optical photography of dry samples, for meltdown tests on elements in flowing sodium and experiments on the effects of fission-product gases.

* * *

This work was performed under the auspices of the U. S. Atomic Energy Commission.

BIBLIOGRAPHY

1. W. J. McCarthy, R. Nicholson, D. Okrent, V. Z. Jankus. Studies of nuclear accidents in fast power reactors, in "Int. Conf. on Peaceful Uses of Atomic Energy," vol. 12, p. 207 (United Nations, Geneva, 1958)
2. G. A. Freund, H. P. Iskenderian, D. Okrent. A pulsed, graphite-moderated reactor for kinetics experiments, in "Int. Conf. on Peaceful Uses of Atomic Energy," vol. 10, p. 461 (United Nations, Geneva, 1958)
3. G. A. Freund, et al., ANL-6034 (1960)
4. F. Kirn, et al., ANL-6173 (1960)
5. D. Okrent, et al., ANL-6174 (1960)
6. E. S. Sowa, NUCLEONICS **12**, No. 6, 122 (1960)
7. D. L. Rall, S. W. Brovarney, ATL-188 (1959)
8. A. B. McIntosh, K. Q. Bagley. Selection of canning materials for reactors cooled by sodium/potassium and carbon dioxide, J. British Nuclear Energy Conf., vol. 3, 15 (1958)
9. G. Golden, ANL-6167 (1960)
10. A. Amorosi, J. G. Yevick, in "Int. Conf. on Peaceful Uses of Atomic Energy," vol. 9, p. 358 (United Nations, Geneva, 1958)

NEWSMAKERS

● **John F. Anderson** has been named assistant to the general manager of Power Reactor Development Co. (PRDC), Detroit, Michigan, the organization building the Enrico Fermi Atomic Plant's nuclear section.

● **Marian Balicki,** member of the Knolls Atomic Power Laboratory advanced concepts activity group, has been named director of AEC's New York Operations Office research div. He will be in charge of research contracts in the 11 Northeastern states which fall under the New York office's jurisdiction.

● **Mark E. Bowles** has joined the Martin Co.'s Nuclear div. as chief engineer of the Martin Nuclear Facility at Quehanna, Penna. He was formerly project engineer with Curtiss-Wright Corp. at Quehanna.

● **G. O. Bright,** a Phillips Petroleum Co. scientist, has taken up his duties at the Instituto Venezolano de Investigaciones Cientificas, Caracas, Venezuela. He will assist in startup and in working out programs for the institute's 3-Mw research reactor. **R. L. Heath** and **W. J. Byron** of Phillips are also serving temporarily as staff members.

● Five additions have been named to the board of directors of Solid State Radiations, Inc., Culver City, Calif.: **Fred Burns,** head of semiconductor operations at SSR, **Allen R. Gruber,** director of Nuclear Systems div., of Marquardt Corp., **Richard L. Gieger,** president of deVegh International; **Erwin Tomahs,** president of Telemeter Magnetics, and **Richard Bellman,** senior mathematician at Rand Corp.

● **Gaelen L. Felt,** formerly staff physicist with the Space Technology Laboratories in the nuclear rocket program, has been appointed manager of the Las Vegas operations of Edgerton, Germeshausen & Grier, Inc., Boston, Mass.

● Three vice presidents have been named by the Nuclear Development Corp. of America, White Plains, N. Y.: **Walter A. Hamilton, William A. Loeb** and **Howard Schwartz.**

● The International Atomic Energy Agency, Vienna, invited **David P. Herron,** the director of Nuclear Technology at Advanced Technology Laboratories, a div. of American-Standard, to assist and advise the agency as a visiting expert. He has participated in studies of nuclear-power cost and nuclear power plant technology.

● **James R. Johnson,** nuclear research and product coordinator for Minnesota Mining & Manufacturing Co., has been named manager of 3-M's applied research department. Other 3-M appointments are: **J. P. Ryan** to project leader for radiochemical products and **H. G. Sowman** to project manager for nuclear materials in 3-M's nuclear production group.

Johnson

● **Howard Reiss,** formerly of Bell Laboratories, has been named associate director of the research department at Atomics International, a div. of North American Aviation, Inc.,

● **John S. Rydz,** former manager of special corporate projects for the Radio Corp. of America, has been appointed executive vice president of the Nuclear Corp. of America, Denville, N. J.

● **Herbert L. Weinberg** has retired as Alco Products' resident manager of SM-1 reactor plant at Fort Belvoir, Va. He is succeeded by **Walter J. Stromquist.**

● **Louis B. Werner** has joined, as a vice president, Hazleton-Nuclear Science Corp., an affiliate of Hazleton-Laboratories, Inc., Falls Church, Va., and Nuclear Science and Engineering Corp., Pittsburgh, Pa. Werner has served as scientific representative with the U. S. Atomic Energy Commission in the U. K. and Ireland. **Frank G. Chambers** has been appointed to succeed **Eugene Zuckert,** now Secretary of the Air Force, as Hazleton's board chairman.

Werner

LepeL
HIGH FREQUENCY
Induction
HEATING
UNITS

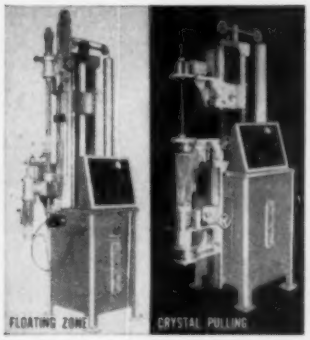
Lepel induction heating equipment is the most practical and efficient source of heat developed for numerous industrial applications

DUAL PURPOSE
FLOATING ZONE AND
CRYSTAL PULLING FIXTURE

A new fixture with separate attachments for crystal pulling and floating zone applications for use with a high frequency induction heating generator.

THE FLOATING ZONE METHOD is used extensively for zone refining and for growing crystals of high purity silicon for semiconductor devices by traversing a narrow molten zone along the length of the process bar in a controlled atmosphere.

THE CRYSTAL PULLING METHOD is used for growing single crystals of various materials, especially germanium, by bringing a seed of known crystal orientation into contact with the surface of the molten metal and slowly withdrawing the seed, producing progressive crystallization.



The Lepel Model HCP-D consists of the basic unit with the traverse mechanism and all the controls including the controls for the operation of the generator, and the floating zone and crystal pulling attachments. The same basic support, programming and control unit is used in either adaptation. The major variations are in the attachments and the induction coils. The change from one application to the other can be accomplished in a very short time.

Our engineers will process your work samples and return the completed job with full data and recommendations without cost or obligation.

WRITE FOR NEW LEPEL CATALOG

LepeL HIGH FREQUENCY LABORATORIES, INC.
55th ST. & 37th AVE., WOODSIDE 77, N. Y.
CHICAGO OFFICE: 6246 WEST NORTH AVE.

NATIONAL COVERAGE

EMPLOYMENT OPPORTUNITIES

The advertisements in this section include all employment opportunities —executive, management, technical, selling, office, skilled, manual, etc.

Positions Vacant | Civil Service Opportunities | Employment Agencies
Positions Wanted | Selling Opportunities Wanted | Employment Services
Part Time Work | Selling Opportunities Offered | Labor Bureaus

DISPLAYED ——RATES—— **UNDISPLAYED**

The advertising rate is $25.33 per inch for all advertising appearing on other than a contract basis. Contract rates quoted on request.
An advertising inch is measured ⅞" vertically on a column—2 columns—30 inches to a page.
Subject to Agency Commission.

$2.10 per line, minimum 3 lines. To figure payment count 5 average words as a line.
Position Wanted ads are ½ of above rate.
Box Numbers—counts as 1 line.
Discount of 10% if full payment is made in advance for 4 consecutive insertions.
Not subject to Agency Commission.

Send NEW ADS or Inquiries to Classified Adv. Div. of NUCLEONICS, P. O. Box 12, N. Y. 36, N. Y.

NSEC IS GROWING

and we need an outstanding scientist and manager to assume full responsibility for the direction and coordination of all our technical activities. The man we seek is mature, between 35 and 45, has a Ph.D in chemistry or physics and some knowledge of biology, has substantial nuclear or tracer experience and management ability as demonstrated by successful industrial positions. The position title will be Technical Director or Technical Vice President. Compensation, which is open, will include a substantial stock option.

Address inquiries to:

MR. R. A. BRIGHTSEN, *President*
Nuclear Science and Engineering Corporation
P. O. Box 10901
Pittsburgh 36, Pennsylvania

for **POSITIONS** in the **NUCLEAR FIELD...**

WRITE US FIRST!
Use Our Application
No Resume Required

Our national coverage and technical experience in the nuclear field offers the maximum opportunity to achieve your goals.

Confidential Handling
Employer Pays Fee

Write: Arthur L. Krasnow

ATOMIC PERSONNEL, INC.
1518 Walnut St. • Phila. 2, Pa. • PE 5-4908
An Employment Agency for the Nuclear Field

PROFESSIONAL SERVICES

ASTRA, INC.
Consultants For Industry & Government
Nuclear: Nuclear Analysis, Reactor Specifications & Design, Shielding, Health Physics, Criticality Hazards Studies
Space: Radiation Effects, Propulsion, Satellite Power Plants, Planetary Simulators
Advanced Technology: Heat Transfer, Stress Analysis, Thermodynamics, Electronic Data Processing, Cryogenics
Raleigh, N. C. VAnce 8-4386 Cable: "ASTRA"

DIVISION MANAGER
$30,000 PER YEAR
One of our major clients seeking a man at division manager level. Should have engineering and managerial background. Large company experience a must. Supervise 9 departments and 800 personnel in the field of military electronics. Company client will assume all empolyment expenses. Contact in confidence.
ESQUIRE PERSONNEL
202 South State Street, Chicago 4, Illinois

NUCLEAR TECHNOLOGY CORPORATION
Consultants to the Nuclear Industry
Reactor conceptual design, reactor physics, heat transfer and fluid flow, shielding, reactor mechanical design, hazards evaluation, nuclear economics, reactor evaluation, computer techniques.
President, Joseph De Felice
Irvington, New York LYric 1-8820

NUCLEAR CALENDAR

April 13–14—Conference on Radioisotopes in the Mining Industry, Denver, Colorado (*Brown Palace*). Co-sponsors: American Mining Congress and the Colorado School of Mines Research Foundation in cooperation with the Office of Isotopes Development, AEC. Contact: AMC, 1102 Ring Building, Washington 6, D. C.

April 21—Yankee Atomic Plant All-Day Symposium, New York City (*Commodore*). Sponsor: New York Metropolitan Section, American Nuclear Society. Contact: C. A. Streifus, Ebasco Service Inc., 2 Rector St., New York City.

April 26–27—High Temperature Materials Conference, Cleveland, Ohio (*Pick-Carter*). Sponsor: American Institute of Mining, Metallurgical and Petroleum Engineers, Cleveland Section. Contact: D. J. Berger, Clevite Research Center, 540 East 105 St., Cleveland 8, Ohio.

May 15–17—Annual Radiation Research Society Meeting, Washington, D. C. (*Sheraton-Park*). Contact: E. L. Powers, Secretary-Treasurer, Div. of Biological and Medical Research, Argonne National Laboratory, Argonne, Ill.

June 9–17—German Chemical Engineering Congress, Frankfurt am Main, Germany. A sponsor is the Chicago Section of the American Chemical Society. The Society for the Study of Isotopes (Isotopen-Studiengesellschaft) and DECHEMA will hold sessions and lectures in conjunction with ACHEMA's technical meetings. Contact: ACS, 86 East Randolph St., Chicago 1, Ill.

June 12–15—International Conference on Physics of Electronic and Atomic Collisions, Boulder, Colorado. Sponsors: University of Colorado and Office of Naval Research. Contact: B. Bederson, Conference Secretary, New York Univ., N. Y. 53, N. Y.

June 13–15—Joint Semi-Annual Meetings of the American Rocket Society and the Institute of the Aerospace Sciences, Los Angeles, Calif., (*Ambassador*). Contact: James J. Harford, ARS, Executive Secretary, 500 Fifth Ave., N. Y. 36, N. Y., or Robert R. Exter, IAS, Executive Secretary, 2 East 64th St., N. Y. 21, N. Y.

June 26–Aug. 18—Eight-week Institute in Nuclear Physics, Oak Ridge, Tenn. College faculty members are eligible to apply; 20 students will be selected. Contact: Atomic Energy Institute, Univ. Relations div., Oak Ridge Institute of Nuclear Studies, Box 117, Oak Ridge, Tenn.

Nuclear Scientists and Engineers:

A "Different" kind of Staff Expansion at The Knolls Atomic Power Laboratory

Selective program expansion—and commencement of applied research projects in new and promising areas of nuclear reactor and power plant technology—have generated several new openings of unusual potential.

The Laboratory can offer immediate placement in:

Electrical systems design/Instrumentation controls design/Power plant equipment design/Reactor nuclear analysis/Theoretical physics (PhD)/Experimental physics/Statistical methods application (PhD)/Reactor mechanical design/Hydro-thermal engineering computations/Numerical analysis.

Masters Degree Program—KAPL is now considering recent graduates in ME, Met, MetE, ChE, Physics, EE, and Nuclear E for its masters degree program in nuclear engineering in conjunction with Rensselaer Polytechnic Institute. Applicants should have strong interest in the nuclear field and must have graduated in upper 10% of their class. Selection of candidates will be completed by early Spring; classes begin September, 1961. Write for further details.

Forward your resume in confidence to Mr. F. W. Snell, Dept. 48-MD.

Knolls Atomic Power Laboratory
OPERATED FOR A E C BY
GENERAL ELECTRIC

Schenectady, New York

(U.S. Citizenship Required)

NUCLEAR ENGINEERS AND PHYSICISTS

EXPANDED ALLIS-CHALMERS PROGRAM HAS CREATED NEW OPENINGS IN THESE AREAS:

- **PHYSICISTS and SENIOR PHYSICISTS**
  Theoretical and Experimental, for reactor design and critical facility.
- **NUCLEAR ENGINEERS and ELECTRICAL ENGINEERS**
  For reactor control and instrumentation design.
- **METALLURGISTS**
  For nuclear fuel development.
- **OPERATIONS ENGINEER**
  For checkout and operation of systems and reactor. Minimum of three years reactor operation experience, preferably some power reactor background.

Challenging career opportunities . . . Excellent working conditions . . . Liberal employee benefits. Positions open at GREENDALE LABORATORIES (Milwaukee) and WASHINGTON, D. C., locations.

SEND RESUME THAT INCLUDES:
Experience, education, salary range and other details. Replies held in strict confidence . . . all inquiries answered.

ADDRESS TO: John C. Schroeder
Department 1621
Allis-Chalmers
Milwaukee 1, Wis.

A-C ALLIS-CHALMERS

FOR BRITAIN

ENGINEERS, PHYSICISTS and MATHEMATICIANS

HINKLEY POINT—500,000 KW ATOMIC POWER STATION
(in construction, commissioning 1962)

SIZEWELL —580,000 KW ATOMIC POWER STATION
(on order and in design)

The English Electric Company Limited of Whetstone, England, has the responsibility for the design and construction of the complete reactors as well as conventional power plant and equipment for these two major atomic power stations, the largest projects of their kind in the world.

The Company is seeking Engineers, Physicists and Mathematicians to participate in this work and also in new developments associated with advanced gas cooled reactors, organic moderated reactors and other systems.

Applicants must hold Masters' or Doctors' Degrees and must be capable of pulling their weight in a team of highly qualified Scientists and Engineers.

Résumés should be sent to E. S. Dean, Room No. 1918, 750 Third Avenue, New York City 17, New York.

Selected Applicants will subsequently be interviewed at convenient locations in the U.S.A. by the Chief Engineer, or his Deputy, of the Atomic Power Division of The English Electric Company Limited.

RADIOCHEMIST

Vallecitos Atomic Laboratory

An experienced radiochemist or radiochemical engineer with 3 to 5 years nuclear background is needed at General Electric's Vallecitos Atomic Laboratory to work in these important areas:

- Studies of the activation, transport, and deposition of corrosion products in Boiling Water Reactors and experimental loops.
- Investigations on the release of fission products from developmental fuels.
- Examination of the radiochemical behavior of new advanced design reactors.

Located in the San Francisco Bay Area, Vallecitos' new Metallurgy and Chemistry facilities offer a stimulating atmosphere to the creative scientist.

Write in confidence to: K. L. Nash

GENERAL ELECTRIC

Dept. B, P.O. Box 254
San Jose, California

Do You Need Experienced Engineers Engaged In:

- Research
- Development
- Design
- Production
- Control
- Instrumentation
- Mechanical
- Chemical
- Other Fields?

No matter in what field of specialization an engineer belongs, there is at least one McGraw-Hill publication he claims as his professional literature. Through its consistently high calibre editorial content, he keeps abreast of technological developments in the industry to which he contributes his experience.

You can reach him through the "EMPLOYMENT OPPORTUNITIES SECTION" of NUCLEONICS.

The selective circulation of NUCLEONICS offers you an opportunity to choose the best qualified men available throughout the industry.

For Rates and Information—Write:

McGRAW-HILL PUBLISHING CO., INC.
Classified Advertising Division
Post Office Box 12
New York 36, New York

INDEX TO ADVERTISERS

A McGRAW-HILL PUBLICATION
ABP ABC
Member of Associated Business Publications and Audit Bureau of Circulations

* AMF Atomics, A Division of American Machine & Foundry 141
Acromag Incorporated 150
Advanced Technology Laboratories, A Division of American-Standard 46
Aero Research Instrument Company, Inc. 44
* Aerojet-General Corporation 119
* Allis-Chalmers 49–52
* American Smelting & Refining Company, Federated Metals Division 41
* American Tradair Corp., Ekco Electronics Ltd. 129
* Anton Electronic Laboratories Inc. 144
* Atomics International, A Division of North American Aviation, Inc. 8, 14
* Babcock & Wilcox Company 1
* Baird-Atomic, Inc. 115
Bell Telephone Mfg. Co. 134
Borden Chemical Company 138
* Branson Instruments, Inc. 44
CPC Engineering 112
* Central Research Laboratories, Inc. 17
* Charleston Rubber Company 148
Continental Sensing, Inc. 118
* Convair, A Division of General Dynamics 45
* Crystals Division Isotopes, Inc. . . . 136
* Curtiss-Wright Corporation 120
* Del Electronics Corporation 150
Delta Chemical Works, Inc. 149
DuMont Laboratories, Allen B. Division of Fairchild Camera & Instrument Corp. 127
* E. M. I. Electronics Ltd. 136
* Edgerton, Germeshausen & Grier, Inc. 107
* Ex-Cell-O Corporation 109
Fenn Manufacturing Company . . . 48
* Fisher Governor Company 47
Gaertner Scientific Corporation . . 106
* General American Transportation Corp. 103
General Astrometals Corp. 149
General Atomic Europe 113
General Dynamics/Electronics Military Products Division 39
* General Electric Company Ltd. of England-Simon Carves, Ltd. . . . 135
General Motors Corp., Allison Division . . . . . Inside front cover
* Great Lakes Carbon Corporation 15
* Griscom-Russell Company 125
Hamilton Manufacturing Company 128
* Harshaw Chemical Company 13
* Haws Drinking Faucet Co. 112
* Hughes Aircraft Company 16, 38
IBM Corporation Data Processing Division 123
* Instrumentation Associates 146
International Instruments Inc. 118
Jerpbak Bayless 44
Krueger Fabricating Co., Inc. 145
* Landis & Gyr, Inc. 148
* Landsverk Electrometer Company 19
Lepel High Frequency Laboratories, Inc. 151
* Linde Company Division Union Carbide Corporation 137
* Lockheed Nuclear Products Georgia Division . . . . . 3rd cover
* Loma Machine Mfg. Co., Inc. . . . 146
Los Alamos Scientific Laboratory . . 124
* Manco Mfg. Company 132
* Martin Company, The 5, 117
* Metals & Controls Inc. A Corporate Division of Texas Instruments Incorporated 111
* Minneapolis-Honeywell . . 42, 43, 116
* National Carbon Company Division of Union Carbide Corporation 36, 37
* Nuclear-Chicago Corporation . . 34, 35
* Nuclear Data, Inc. 9–12
* Nuclear Development Corp. of America 20
* Nuclear Enterprises, Ltd. 143
* Nuclear Materials & Equipment Corp. 145
* Nuclear Measurements Corp. 130
Oak Ridge Technical Enterprises Corporation 133
* Philips Gloeilampenfabrieken N. V. 108
* RCA Service Company 7
* Radiation Counter Laboratories, Inc. 33
Radiation Dynamics, Inc. 101
* Radiation Instrument Development Laboratory, Inc. 105
* Radio Corporation of America, Industrial Electronics Products . . . 133
* Saint-Gobain Nucleaire 147
St. Petersburg Chamber of Commerce 40
Sciaky Bros., Inc. 131
* Solid State Radiations, Inc. 6
* Teleflex Incorporated 2
* Texas Instruments Incorporated Metals & Controls, Inc. 111
Ultek Corporation 139
Valcor Engineering Corporation . . 121
Vapor Blast Mfg. Company 136
* Victoreen Instrument Company 4th cover
* Vitro Chemical Company, a Subsidiary of Vitro Corp. of America 104
Westinghouse Atomic Power Division 18
Zirconium Corporation of America 146

*** See the advertisement in the November, 1960 issue of Nucleonics Buyer's Guide for complete line of products and services.**

PROFESSIONAL SERVICES 152

CLASSIFIED ADVERTISING
F. J. Eberle, Business Mgr.

EMPLOYMENT OPPORTUNITIES 152–154
Allis Chalmers 153
Atomic Personnel Inc. 152
English Electric Ltd. 154
Esquire Personnel 152
General Electric 153, 154
Nuclear Science and Engineering Corp. 152

This index is published as a service. Every care is taken to make it accurate, but NUCLEONICS assumes no responsibility for errors or omissions.

NUCLEONICS ADVERTISING SALES REPRESENTATIVES

NEW YORK:
Donald J. Cassidy
500 Fifth Ave.
New York 36, N. Y.
OXford 5-5959

BOSTON:
Merrill J. Hosmer
McGraw-Hill Building
Copley Square
Boston 16, Mass.
COngress 2-1160

PHILADELPHIA:
Donald C. Knapp
Six Penn Center Plaza
Philadelphia 3, Pa.
LOcust 8-4330

CHICAGO:
Willis T. Smith
520 N. Michigan Ave.
Chicago 11, Ill.
MOhawk 4-5800

CLEVELAND:
Thomas K. Cogswell
55 Public Square
Cleveland 13, Ohio
SUperior 1-7000

LOS ANGELES:
Frederick R. Whitmore
1125 West Sixth St.
Los Angeles 17, Calif.
HUntley 2-5450

PORTLAND:
Scott Hubbard
Room 445, Pacific Bldg.
Yamhill Street
Portland 4, Oregon
CApital 3-5118

ATLANTA:
M. H. Miller
McGraw-Hill Pub. Co., Inc.
1375 Peachtree St., N.E.
Atlanta 9, Georgia
ATlanta 875-0523

DALLAS:
John G. Grant
McGraw-Hill Pub. Co., Inc.
901 Vaughn Bldg.
1712 Commerce St.
Dallas 1, Texas
Riverside 7-9721

HOUSTON:
Joseph C. Page
McGraw-Hill Pub. Co., Inc.
Prudential Bldg., W-724
Holcombe Blvd.
Houston 25, Texas
JAckson 6-1281

DENVER:
John W. Patten
McGraw-Hill Pub. Co., Inc.
Tower Bldg.
1700 Broadway
Denver 2, Colo.
ALpine 5-2981

LONDON:
Edward E. Schirmer
Dennis McDonald
McGraw-Hill Pub.Co.,Ltd.
34 Dover St.
London W1, England

FRANKFURT:
Stanley R. Kimes
McGraw-Hill Pub. Co., Inc.
85, Westendstrasse
Frankfurt/Main, Germany

GENEVA:
Michael R. Zeynel
McGraw-Hill Pub. Co., Inc.
2, Place du Port
Geneva, Switzerland

The Nuclear Space Age

As the special report in this issue brings out, the U. S. is on the threshold of an era which some are already calling "The Nuclear Space Age"—the joining in inevitable matrimony of two of contemporary man's most exciting frontiers, nuclear energy and outer space. Upon the early and successful crossing of these two frontiers—to produce the nuclear rocket—may well depend the long-term success of the U. S. space program.

This country has embarked on a major space program for several reasons—not all of which are clear. But certainly three of them must be: (1.) survival; (2.) competition with the Russians for both propaganda and self-esteem reasons; and (3.) man's natural curiosity. The nuclear rocket, it is now clear, is of basic importance on all of these points, collectively or separately. Because of its potential for doubling or tripling spacecraft payload capabilities of chemical systems, it offers the only realistic possibility for overcoming the space-payload lead of the Soviet Union. Moreover, if the nuclear-rocket is *not* developed with alacrity in the U. S., but *is* so developed by the Soviets, their lead would become virtually insurmountable. In short, the nuclear rocket gives this country its only chance to catch up with—indeed to surpass—the U.S.S.R.

Unfortunately, the opportunity offered by nuclear rocketry may not be recognized by all in a position of influence in the federal government. The Eisenhower Administration generally failed to grasp its significance as *the* rocket system of the future. Then, the Kennedy Administration gave the early impression that it might actually seek to downgrade the program. An advisory group to the new president, headed by his science advisor, Jerome B. Weisner, made it clear in a report on space in January that the group felt no urgency for nuclear-rocket development (page 54). Among other things, the committee said: " . . . the technology is so new and the extrapolation from reactors developed now to sizes which would be useful in large rockets is so great that it is not clear how soon they will make an important contribution to the space program. . . . A major technical and management review of the Rover program seems urgent."

There is a real danger here. It lies in the possibility that the nuclear rocket could be diverted from its present course, which leads toward early engine development and, instead, be turned toward a research and development effort not tied to any particular flight-test target. Let us simply point to the 10-year-old Aircraft Nuclear Propulsion program as a tragic refutation of this philosophy.

Los Alamos Scientific Laboratory has capably brought nuclear-rocket technology to the point of initial engine design. Harold B. Finger, nuclear-rocket manager for AEC and NASA, has laid out a realistic flight-test target and mission goal for the first rocket vehicles (page 58). In addition, he has impressed the scientists, industrialists and government officials with whom he must work as a man who can do the job.

What is needed now? First, a policy declaration by the Administration—preferably external, as well as internal—that the nuclear rocket program is considered vital to the nation's space program. Second, that it will receive the financial and policy support commensurate with its importance.

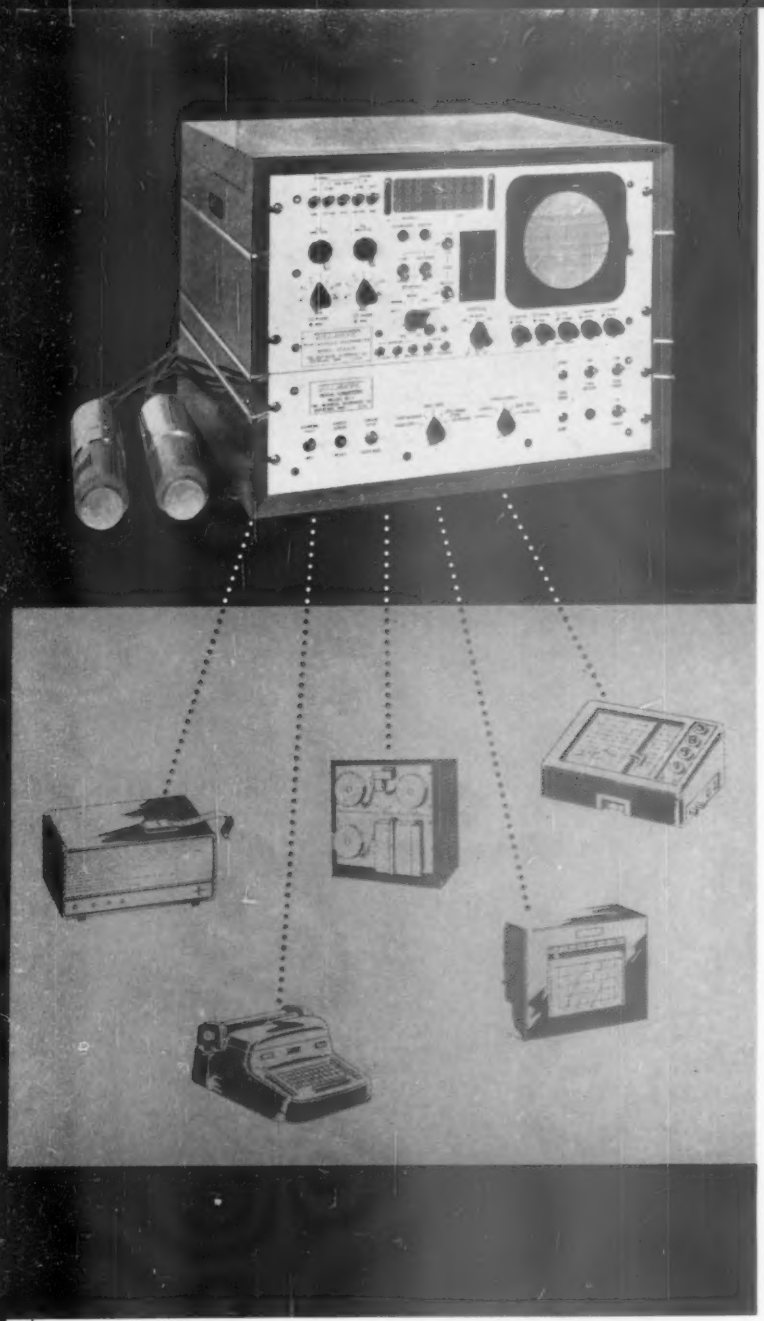
The government must get behind this program and give it all-out support. We have been second-best in space long enough.

BIOMEDICAL IRRADIATION

This transparent plastic man illustrates one of the many biomedical studies being conducted in the Lockheed-operated Georgia Nuclear Laboratories (Air Force Plant 67) near Dawsonville, Georgia. This facility is the only one with the capacity to accommodate large numbers of specimens, so that statistically reliable measurements may be made. The ten-megawatt reactor can irradiate six carloads of biomedical specimens, subsystems, or components simultaneously under operational conditions. Space and other environments can be simulated.

Address: Lockheed Nuclear Products, 1500 Northside Drive N. W., Atlanta 18, Georgia.

LOCKHEED GEORGIA



Victoreen

Victoreen, the first name in radiation measurement, is delivering the last word in multi-channel analyzers—the Tullamore-designed Model ST-200D

- 200 or 400 Channel ferrite core memory
- Dual input—Simultaneous data accumulation
- Subgrouping and bi-directional logic
- Parallel or serial readout—Wide selection of readout devices
- Visual display and readout—Linear, log or both simultaneously
- Simultaneous linear and log plot

A-8033A

Service by
RCA SERVICE COMPANY
A Division of Radio Corporation of America

V I C T O R E E N
5806 HOUGH AVENUE • CLEVELAND 3, OHIO
EXPORT: 240 WEST 17TH ST. • NEW YORK 17, NEW YORK

N

OHIO

YORK